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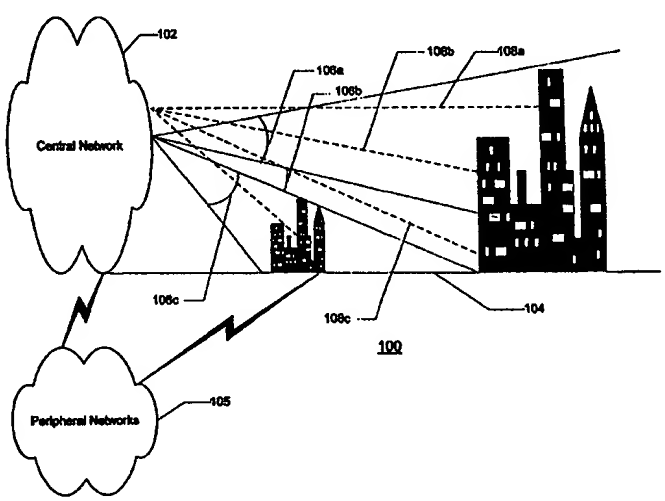

(57) Abstract

A system and method for networked high-speed data communication through free space is described. The system includes one or more central networks, which contain one or more lasers modulated with high-speed data to illuminate with laser light areas surrounding the central network in which are located one or more user networks. The laser from the central network generates a radiation pattern that is sectored into horizontal and vertical sectors, and further divided into channels for each wavelength. Data coming from the user networks modulates a laser, which is transmitted as a collimated beam through free space back to the central network where it is received. Communication can be point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint, and the point-to-multipoint communication can be broadcast, simulcast, or multicast.

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OPTICAL COMMUNICATION SYSTEM THAT TRANSMITS AND RECEIVES DATA THROUGH FREE SPACE

TECHNICAL FIELD

The present invention is related generally to data communication systems and, in particular, to free space optical data communication networks.

BACKGROUND OF THE INVENTION

Existing telecommunication systems may be useful for providing traditional telecommunication services, but generally are confined to relatively low-speed, low-capacity applications. For example, standard telephone lines are limited to data rates of approximately 60 kilobits per second (Kbps) per telephone line, well-known Integrated Services Digital network (ISDN) services provide data rates up to 128 Kbps, and Asymmetrical Digital Subscriber Line (ADSL) services are limited to eight megabits per second (Mbps) data rates. Similarly, conventional satellite networks can deliver data to end users at up to 30 Mbps per satellite, and Local Multipoint Distribution Services (LMDS) appear to have an upper limit of about four to eight gigabits per second (Gbps) per two km cell. These data rates, especially when divided between multiple users, soon prove to be insufficient for many modern applications. such as video teleconferencing and multimedia applications.

Because a typical personal computer can transmit and receive data via Ethernet at data rates in excess of 100 Mbps, individuals and businesses alike may find attractive telecommunication services that accommodate those data rates. For example, many customers may desire high-speed data communication for use with the Internet and the World Wide Web, high resolution video teleconferences, video telephony, large multi-gigabyte file transfers, etc. This means that for telecommunication service providers to thrive in today's globally competitive environment, any future telecommunication system must meet these demands without unreasonable costs.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a block diagram of a communication system suitable for implementing an embodiment.

Figure 1B is an isometric view showing a side of the communication system of Figure 1A.

Figure 2 is a block diagram of an illustrative central network components for downlink transmission using the communication system in Figure 1B.

Figure 2A is a flow diagram of an illustrative central system controller transmit function.

Figure 3 is a block diagram of illustrative user network downlink reception components.

Figure 3A is a flow diagram of an illustrative user system controller transmit function.

Figure 3B is a flow diagram of an illustrative user system controller receive function.

Figure 4 is a block diagram of illustrative central downlink signal processor components.

Figure 5 is a block diagram of illustrative user downlink signal processor components.

Figure 6 is a flow diagram of an illustrative downlink data transmission and reception process.

Figure 7 is a block diagram of illustrative user network uplink transmission components.

Figure 8 is a block diagram of illustrative central network uplink reception components.

Figure 9 is a block diagram of illustrative user uplink signal processor components.

Figure 10 is a block diagram of illustrative central network uplink components.

Figure 11 is a flow diagram of an uplink data transmission and reception process.

Figure 12 illustrates a data packet suitable for use with the communication system of Figure 1A.

Figure 13 illustrates an illustrative transmission point with sectorization.

Figure 14 illustrates examples of various suitable radiation patterns generated by the central transmit antennas in the illustrative central network components of Figure 2.

Figure 15 illustrates an illustrative topography produced by the sectorization of Figure 13.

Figure 16 is a flowchart illustrating an illustrative multicast process.

Figure 17 shows an illustrative central input/output interface.

Figure 18 is a block diagram showing an alternative embodiment of the communication system of Figures 1A and 1B.

In the figures, like reference numbers refer to similar elements. In addition, the most significant digit in a reference number refers to a figure in which that element is first introduced (*e.g.*, an element 204 is first introduced in Figure 2).

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

A communication system, and in particular, a system and method for optical communications in free space is described herein. In the following description, numerous specific details, such as specific symbols and relationships, specific methods of and structures for transmitting, receiving, and processing high speed data, etc., are set forth to provide a full understanding of embodiments of the invention. One skilled in the relevant art, however, will readily recognize that the invention can be practiced without one or more of the specific details, or with other methods and structures, etc. In other instances,

well-known structures or operations are not shown in detail to avoid obscuring the description of the embodiments.

Embodiments of the invention are directed to systems, methods, and interconnected devices for networked, high-speed, bi-directional data communication through free space having one or more centrally located transmit/receive stations which use one or more lasers modulated with encrypted, high-speed (10 Mbps-10 Gbps) data and control signals to illuminate with laser light some or all of the areas surrounding the centrally located transmit/receive stations. The illuminated areas surrounding the centrally located transmit/receive stations encompass one or more user optical receivers having light gathering and filtering elements, active tracking devices, optical detectors, and demultiplexing and decoding circuitry, which receive and select portions of the centrally located transmit/receive stations laser high-speed data stream for output to a user optical transceiver interface output, which is in turn may be connected via a high-speed networking connection to user equipment.

Data coming from user equipment on a 100 Mbps megabit Ethernet goes to the user optical transceiver interface input and modulates a laser collocated in the user optical transceiver. The user optical transceiver sends a collimated laser beam through free space back to the centrally located transmit/receive stations, where the collimated laser beam is received by light gathering and filtering elements, and active and actively tracking matrix detectors, where the data is detected and directed into data routing circuits. The data routing circuits route the data to node addresses, which can be either within one centrally located transmit/receive station area or within other centrally located transmit/receive station areas, via a high-speed free space optical backbone network-to-network links or anywhere on other networks connected to the centrally located transmit/receive stations(s) routing circuitry.

The centrally located transmit/receive stations routing circuitry also routes incoming data addressed to any or all user optical transceiver(s) by encoding that data into the high-speed data stream of the particular centrally

located transmit/receive station laser being detected by the respective user optical transceiver. The laser beams illuminate the area surrounding the centrally located transmit/receive stations in a variety of radiation patterns. The radiation patterns are sectored horizontally (or radially) and/or vertically (or by elevation). The sectors may be further subdivided into several wavelength channels. The networks transmit and receive data using the channels.

Of course, those skilled in the art will appreciate that the invention is not limited to this embodiment. Instead, the invention supports a variety of embodiments, some of which are described more fully below.

The Communication System

Figure 1A is a block diagram of a communication system **100** suitable for implementing an embodiment. The communication system **100** can be thought of as a hierarchic system with a set of interconnected networks, where each network is a node in the communication system **100**, and where each network is interconnected. For example, the communication system **100** can include as nodes one or more central networks **102**, user networks **104**, and/or peripheral networks **105**.

Data is exchanged among the networks. In one embodiment of the invention, data is sent from the central networks **102** to the user networks **104** using shaped and diverging coherent light beams (or light cones) **106**, and data is sent from the user networks **104** to the central networks **102** using collimated light beams **108**. Each individual network also can include a hierarchy of interrelated subsystems with lower level nodes (or network elements), which is described more fully below. Data is exchanged among the networks point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint, and point-to-multipoint communication can be broadcast, multicast, or simulcast.

For example, during point-to-point communication, any one of the central networks **102** or their lower level nodes can transmit data from itself to any one node in the user networks **104** or the peripheral networks **105**. Likewise,

any of the central networks **102** or their lower level nodes can receive data from any one of the user networks **104** or their lower level nodes, as well as from any one of the peripheral networks **105** or their lower level nodes.

During point-to-multipoint communication, any one of the central networks **102** or their lower level nodes can transmit data from itself to several user networks **104** or their lower level nodes substantially simultaneously. Any one of the central networks **102** or their lower level nodes can transmit data from itself to several peripheral networks **105** or their lower level nodes substantially simultaneously. Likewise, any of the central networks **102** or their lower level nodes can receive data from any of the user networks **104** or their lower level nodes substantially simultaneously, as well as from any of the peripheral networks **105** or their lower level nodes substantially simultaneously.

The hierarchy of the communication system **100** can feature networks interconnected with each other, as Figure 1A illustrates. The embodiment does not require that the peripheral networks **105** and the user networks **104** be interconnected, or that the central networks **102** be connected to both the peripheral networks **105** and the user networks **104**. Moreover, the central networks **102** may be interconnected to each other such that data is transmitted among the individual central networks **102** without passing through a peripheral network **105** or a user network **104**. This particular embodiment reduces the costs of operation, for example, by allowing central networks to carry their own backbone traffic, unlike other wireless networks that dedicate all of their bandwidth to the user networks.

In one embodiment of the invention, a user network **104** is operated by a user that subscribes with the peripheral networks **105** and/or the central networks **102** to send and receive data in a client-server environment. The users may be located at a manufacturing facility, a multinational corporation, a financial institution, or a university, for example, with buildings that house the network components. In that instance, the central networks **102**, the user networks **104**, and the peripheral networks **105** connect "client" systems with

"server" systems so that the server systems may perform a computation, retrieve a file, or search a database for a particular entry in response to a request by the client system. A particular type of client-server environment is not essential to the embodiment. It will be apparent to those skilled in the art that the embodiments may be implemented in other client-server environments, such as airline flight reservations systems, mail-order facilities, etc.

The peripheral networks **105** can be any interconnected network operated by a common carrier, including a Public Switched Telephone Network (PSTN), a Local Exchange Carrier (LEC) network providing local telecommunication services, an Interexchange Carrier (IXC) providing long distance telecommunication services, a satellite network, a value added network (*e.g.*, providing dial-up stock market quoting services, electronic mail services, etc.). Alternatively, the peripheral networks **105** can be a collection of networks functioning as a virtual network, including the Internet, the World Wide Web, etc. The peripheral networks **105** also can include data communication networks such as Local Area Networks (LANs), Metropolitan Area Networks (MANs), or Wide Area Networks (WANs). Of course, those skilled in the art will appreciate that a particular type of peripheral network **105** is not required by the embodiment. Instead, any type of peripheral network **105** may be used.

In one embodiment, the central networks **102**, the user networks **104**, and the peripheral networks **105** utilize Synchronous Optical Network (SONET) technology, which is an optical interface standard that allows internetworking of transmission products from multiple vendors. That is, when the communication system **100** implements SONET technology, interconnection of the networks enables worldwide data communication. Moreover, when the communication system **100** implements SONET technology, a new digital hierarchy ideally suited to handling fiber-based signals and at the same time allowing easy extraction of lower rate signals is accomplished. These include unified operations and maintenance and the flexibility to allow for future service offerings.

In an alternative embodiment, the central networks **102**, the user networks **104**, and the peripheral networks **105** utilize Gigabit Ethernet technology, which is an optical interface standard that allows internetworking of transmission products from multiple vendors. That is, when the communication system **100** implements Gigabit Ethernet technology, interconnection of the networks enables worldwide data communication, especially real-time voice and video and high-end server support. Moreover, when the communication system **100** implements Gigabit Ethernet technology, a new digital hierarchy ideally suited to handling fiber-based signals and at the same time allowing easy extraction of lower rate signals is accomplished. These include unified operations and maintenance and the flexibility to allow for future service offerings.

Figure 1B is an isometric view showing a side of the communication system **100**, where data is exchanged between the central networks **102** and the user networks **104** in free space using the light cones **106a-c** and the collimated light beams **108a-c**. In one embodiment, the light cones **106a-c** are shaped and diverging coherent light beams, such as light amplification of stimulated emission of radiation, or "laser" beams. Laser beams are directional, and can operate in a range of wavelengths in the "light" region of the electromagnetic spectrum, including visible light, near-infrared light, and infrared light. When the light cones **106a-c** are laser beams, the light cones **106a-c** accommodate high bit rate, high power, high coupling efficiency, direct high frequency modulation, and long haul operations. In one embodiment, the light cones **106a-c** are eye-safe, class one laser beams, in accordance with American National Standards Institute (ANSI) standards. In alternative embodiments, the light cones **106a-c** operate in accordance with other ANSI standards.

The use of particular wavelengths of laser light provides high bandwidth with very little attenuation (or power loss) in the atmosphere. Moreover, using laser light allows interconnection with SONET architectures

operating at high speeds between central networks **102** typical of off-the-shelf data transmission equipment currently available. Moreover, in this embodiment, using the SONET protocol allows arbitrary bandwidth allocation in the well-known portions of T-1 capacity. That is, when the communication system **100** uses the laser lights with SONET, it can accommodate a digital transmission link with the capacity of 1.544 Mbps to many different users across remote distances.

One embodiment of the communication system **100** uses an infrared laser with a wavelength of approximately 1550nm. Of course, those skilled in the art will appreciate that a particular wavelength in the light region of the electromagnetic spectrum is not required by the embodiment. Instead, any wavelength in the light region may be used.

The light cones **106a-c** and the collimated light beams **108a-c** can be generated using any well-known holographic optical elements that shape, filter, and diverge or collimate the light appropriately. For example, beam shaping can be accomplished using diffraction gratings, lenses, holographic optical elements, or other standard beam-shaping optic. Wavelength filtering, used in various channelization schemes, can also be achieved using a variety of standard optical components such as interference filters, diffraction gratings, or prisms.

As is described more fully below, the light cones **106a-c** bit rate in one embodiment may be between 10 Mbps and 10 Gbps, inclusive. Of course, those skilled in the relevant art will appreciate that a particular data rate is not required for the embodiment. That is, the embodiments of the invention support any number of data rates.

As is the case with the light cones **106a-c**, the collimated light beams **108a-c** also can be laser beams or any light beam at a wavelength in the "light" region of the electromagnetic spectrum, including visible light, near-infrared light, and infrared light. Collimating can be accomplished in a well-known manner, such as by using a diffraction gratings, lenses, or other standard beam-shaping optics.

Of course, those skilled in the art will appreciate that, while much of the communications within the communication system **100** involves the wireless exchange of extremely high-speed. broadcast, digital data, the communication network **100** also supports conventional methods of data communication, such as telephone lines. For example, a central network **102** can transmit Internet video data at an extremely high speed to a user network **104** using a light cone **106a**, with the return communication from the user network **104** to the central network **102** being via a standard telephone line. This may be the case when the Internet data is graphics and text, and the user data is credit card information, for example. This also may be the case when the Internet data is graphics and text, and the user data is user authorization information, for example.

Moreover, those skilled in the art will appreciate that, while the communication system **100** can involve the wireless exchange of extremely high-speed, broadcast, digital data, the communication system **100** can use other data rates. That is, the communication system **100** can communicate at data rates commensurate with the type service being provided, the quality of service requested, type of information transmitted and/or received, etc.

Downlink Transmission and Reception Structure

Figure 2 is a block diagram of illustrative central network **102** downlink transmission components. In this embodiment, the peripheral networks **105** send data for transmission to the user networks **104** via a central router/switcher **204**, a central downlink signal processor **206**, and a central transmit antenna **208**. A central system controller **210** controls the operation of the central router/switcher **204** and the central downlink signal processor **206**. Generally, data travels along the thick interconnection lines, while other commands, control signals, etc., travel along the thin interconnection lines. Data and other commands, control signals, etc., may also travel on thin and thick interconnection lines, respectively.

For purposes of explanation, only one central network **102** is described with respect to certain aspects of the embodiment of Figure 2. It is to be understood that the embodiment contemplates one or more central networks **102**.

The central router/switcher **204** connects the central network **102** to the peripheral networks **105** and to the user networks **104**, enabling data to be exchanged between them. The central router/switcher **204** can interconnect network interface controllers (NICs), disk controllers, graphic display adapters, etc., to the central network **102**. For example, the central router/switcher **204** supports NICs implemented in a G-NIC Network Interface Card available from Packet Engines of Spokane, Washington, adapted from 830nm to 1550nm.

Other illustrative central router/switcher **204** implementations include well-known 10/100 Mbps Ethernet NICs with 64-bit Peripheral Component Interconnect (PCI) buses, which support either Windows NT™ or the Digital UNIX® operating system. When the peripheral network **105** is the Internet, the central router/switcher **204** can support Internet points of presence (POPs).

The central router/switcher **204** in one embodiment is a fiber optic backbone that interconnects lower level network elements in the peripheral networks **105** or the central networks **102**. In that embodiment, and where the communication system **100** is a packet-switched network, the central router/switcher **204** is the main path for data packets. Packet-switched networks are described more fully below.

The central router/switcher **204** also interconnects the components that transmit the light cones **106** and receive the collimated light beams **108**. The central router/switcher **204** manages the routing of data through the communication system **100**. For example the central router/switcher **204** divides the central network **102** into logical software-oriented sub-networks, enabling data traffic to be more efficiently routed. The central router/switcher **204** also performs load balancing, partitioning, and statistical analysis on data traffic. The

central router/switcher **204** also determines routing priorities, and performs troubleshooting tasks. The central router/switcher **204** also selects the paths that data from the light beam **108** or data to the light cone **106** will take in the communication system **100**. The central router/switcher **204** may dynamically route data based on the quality of service required or the amount of data traffic in the central network **102**.

In one embodiment, the central router/switcher **204** implements a link state routing algorithm that calculates routes based on the number of routers, transmission speed, delays, and route costs. This embodiment can be implemented using an "open shortest path first" (OSPF) protocol running on a PowerRail 5200 Gigabit Ethernet routing switch available from Packet Engines. The central router/switcher **204** also includes several queues that hold data waiting to be routed.

The central downlink signal processor **206** receives the data to be sent to the user networks **104** from the central router/switcher **204** and encodes, modulates, encrypts, buffers, and amplifies the data to produce a carrier whose frequency is in the visible or near-infrared region of the electromagnetic spectrum. A carrier with such a high frequency is sometimes referred to herein as an "optical signal," an "optical carrier," a "carrier," a "carrier signal," a "lightwave signal," a "light cone," or a "light beam."

The central downlink signal processor **206** also shapes the carrier signal for transmission by the central transmit antenna **208**. The structure and operation of the central downlink signal processor **206** is described in greater detail below with reference to Figure 4, including queuing of data waiting to be processed.

The central transmit antenna **208** transmits the carrier into free space. For purposes of explanation, only one central transmit antenna **208** is described with respect to the illustrated embodiment of the invention. It is to be understood that the embodiment can contemplate one or more central transmit

antennas per local central network and one or more central networks per geographic location.

According to an embodiment, the central transmit antenna **208** transmits the carrier into free space using geometric optics, such as refractive, reflective, diffractive, or holographic optics. Imaging geometric optics (IGOs) have the capability of making an image of an object. The image may either be a "real image" or a "virtual image." A real image is one that is cast on a screen, for example. A virtual image is viewed through an eyepiece.

To accomplish this task, an IGO has two properties: (1) Parallel light rays passing through the optics are focused to a single point (the "focus"); and (2) Light rays incident from different angles are focused to different foci, all of which lie in a plane (the "focal plane"). A telescope, camera lens, shade projector, magnifying lenses, and contact lenses are examples of imaging geometric optics.

Non-imaging geometric optics (NGOs) do not satisfy at least one of the criterion necessary for an IGO. If one tries to observe an image created by NGOs, the image will either be "fuzzy" or nonexistent. Examples of NGOs are the Fresnel lenses used in front of motor vehicle headlights or the rippled "privacy" glass used in certain windows where privacy is required.

A diffraction grating is an example of an NGO suitable for implementing one embodiment of the invention. Of course, any diffraction grating suitable for focusing the desired wavelength that can focus the light cone **106** into a small enough spot could be used. In this embodiment, a diameter for the light cone **106** is 60 microns. Those skilled in the art will appreciate that the particular diameter is dependent upon the desired data rate.

Although IGOs are adequate, they are expensive and the embodiment does not require all of their capabilities. Thus, one embodiment uses NGOs to maximize the utility of the system while minimizing the cost of the transmit and receive optics. A suitable non-imaging geometric optic operating in the 1550nm range is available from Richardson Labs in Meridian, Idaho.

The central system controller **210** controls the operation of the central router/switcher **204**, and the central downlink signal processor **206**. The central system controller **210** can be implemented in hardware, software, or a combination of both hardware and software. In aspects that are implemented using software, the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.). The central system controller **210** may also be custom software running on a composite of computers (or processors).

Figure 2A illustrates a flow diagram of a central system controller **210** transmit function **200** suitable for implementing the custom software running on a composite of computers. Operation of the transmit function **200** begins with step **211**, where control immediately passes to step **212**. In step **212**, the transmit function **200** determines which of its data queues advances next to send data to the central downlink signal processor **206**. In step **214**, the transmit function **200** synchronizes encoding and multiplexing schemes. In an embodiment, a user system controller **310** (*see*, *e.g.*, Figure 3) synchronizes encoding and multiplexing schemes with the user networks **104**. That is, the central system controller **210** performs handshaking with the user networks **104** to initiate a data transfer.

In step **216**, the transmit function **200** determines the particular encoding required. Typically, the user networks **104** control the encryption scheme, while the central networks **102** control the multiplexing and encoding schemes. Thus, in an embodiment, the central controller **210** determines the particular encoding required.

In step **218**, the transmit function **200** decides when a data packet is to be transmitted. In an embodiment, the central system controller **310** makes this decision. Operation of the transmit function **200** is complete following step **218**, as indicated by step **220**.

The output of the central networks **102** on the downlink are the light cones **106**, which are transmitted into free space and received by the user networks **104**. That is, each of the central networks **102** transmits data modulated on a shaped and diverging coherent or other light beam through free space.

Figure 3 is a block diagram of illustrative user network **104** downlink reception components. A user antenna **302** receives data transmitted from the central network **102**, processes it using a user downlink signal processor **304**, and sends the data to user equipment and devices **308**, the user system controller **310**, and/or any of the peripheral networks **105**. For purposes of explanation, only one user network **104** may be described with respect to certain aspects of the embodiment shown in Figure 3. It is to be understood that embodiments of the invention contemplate one or more user networks **104**.

As mentioned above, the user antenna **302** receives the light cones **106** from free space. The user antenna **302** receives the light cones **106** using an optical receiving antenna, which, in one embodiment, uses holographic optical elements. One embodiment uses well-known telescopes to receive the light cones **106**. For example, the user antenna **302** can be a reflective telescope with a modified eyepiece to further confine the spot size of the received light. The user antenna **302** outputs the received light cones **106** to the user downlink signal processor **304**.

The user downlink signal processor **304** receives the light cone **106** and decodes, demodulates, decrypts, and buffers it to separate the data from the carrier. The structure and operation of the user downlink signal processor **304** is described in greater detail below with reference to Figure 5.

The user input/output interface **306** interconnects the user equipment **308**, the user system controller **310**, and the peripheral networks **105**. Recall that in one embodiment, the user network **104** is operated by a user that subscribes to send and receive data in a client-server environment, such that the central networks **102**, the user networks **104**, and the peripheral networks **105**

connect "client" systems with "server" systems. The user input/output interface **306** interconnects the client systems with the server systems using appropriate signaling and protocols. In one aspect, the user input/output interface **306** supports well-known full-duplex operation and flow control common to client-server environments. In another aspect, the user input/output interface **306** supports Signaling Network Management Protocol (SNMP), which is a well-known method by which network management applications query a management agent using a supported Management Information Base (MIB). This embodiment manages virtually any network type, to include Non-Transmission Control Protocol (non-TCP) devices, such as IEEE 802.1 Ethernet bridges.

The user input/output interface **306** supports bidirectional encryption, with the ability to change keys as needed. The user input/output interface **306** also implements "challenge" and "reply" authentication when setting the keys. In this embodiment, the user input/output interface **306** has a unique serial number, even though it does not have a unique network address, which serial number can be used for encryption and other security features. The firmware on the subscriber input/output interface **306** also is protected from hacking.

The user equipment and devices **308** can be any of a variety of well-known equipment, such as gateways, local area networks, bridges, etc. The user equipment and devices **308** also can be any of a number of well-known user devices, such as printers, hard drives, graphical display adapters, televisions (TVs), TV set top boxes, telecommunication equipment, video conferencing equipment, and audio/visual equipment, such as home theater electronics, etc.

The user system controller **310** operation and structure are similar to the operation and structure of the central system controller **210**, in that the user system controller **310** controls the operation of the user downlink signal processor **304** and the user input/output interface **306**. The user system controller **310** likewise can be implemented in hardware, software, or a combination of both hardware and software. In embodiments that are implemented using software,

the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.).

The user system controller **310** may also be custom software running on a composite of computers (or processors). In one embodiment, the user system controller **310** is implemented in a token ring time-division multiplex (TDM) system.

Figure 3A illustrates a flow diagram of a data transmit routine **300** suitable for use with the user system controller **310** in this embodiment. The transmit routine **300** begins with step **311**, where control immediately passes to step **312** wherein the transmit routine **300** determines the type, amount, and rate of data to be transmitted.

In step **314**, the transmit routine **300** communicates the information gathered in step **312** to the central system controller **210**. In step **316**, the transmit routine **300** transmits data during the life of the token. In step **317**, the transmit routine **300** determines if no more data exist, and in step **318** returns a token to the central system controller **210**. If in step **318**, no more data returns a token to the central system controller **210**, the transmit routine **300** returns to step **312**.

In step **320**, if there is more data, the transmit routine **300** waits for the next token from the central system controller **210**, and then the transmit routine **300** returns to step **312**.

Figure 3B is a receive routine **350** that the user system controller **310** implements in the token ring TDM system embodiment. For example, in step **352**, the receive routine **350** receives a data packet and demodulates it. In step **354**, the receive routine **350** examines the data packet header, and determines if the data packet address matches a user system address.

In step **356**, the receive routine **350** determines whether the address of the data packet matches the user's system address. If the address is a match, then control of the receive routine **350** passes to step **358**, wherein the receive

routine **350** decrypts the data packet. In step **360**, the receive routine **350** sends the data packet to the user's sub-network.

If, on the other hand, in step **356** it is determined that the data packet address does not match a user system address, operation of the receive routine **350** passes to step **362**, wherein the receive routine **350** dumps the data packet.

Figure 4 is a block diagram of illustrative central downlink signal processor **206** components. The illustrative central downlink signal processor **206** includes encoders **402**, modulators **404**, multiplexers **406**, and power amplifiers **408** that convert data into a carrier, and amplify the carrier for transmission in free space to the user networks **104**.

The encoders **402** convert data into a representation of the data according to a set of rules or conventions specifying the way in which the signals representing the data can be formed, transmitted, received, and processed. In one aspect, the encoders **402** encodes data and control signals into a high-speed data stream. Illustrative encoders **402** are implemented in a Media Access Controller (MAC) chip on Packet Engines' G-NIC. Of course, the encoders **402** can be implemented in any Ethernet card, switch, or repeater with the same encoding capabilities.

The modulators **404** modulate the light cone **106** according to the data to be transmitted on that light cone **106**. There are several types of well-known modulation schemes used for communications (*e.g.*, frequency modulation, phase modulation, phase-shift keying modulation, quadrature amplitude modulation, etc.), any of which are suitable for implementing communication in the communication system **100**. In one embodiment, the modulators **404** are implemented in well-known Ethernet Peripheral Component Interface (PCI) cards whose input and output are via optical fiber. In this embodiment, the modulators **404** use a well-known on-off keying (OOK) amplitude modulation scheme. The OOK amplitude modulation scheme is the lowest cost modulation scheme currently available. Of course, the modulators

404 can be implemented in any Ethernet card, switch, or repeater with the same modulating capabilities. An embodiment uses the serializing/deserializing chip on Packet Engines' G-NIC to implement the modulation task, as well as to drive the laser.

The multiplexers **406** in one aspect are wavelength division multiplexers (WDMs) that establish optical channels by combining the wavelengths (or colors) into the light cone **106**. That is, the multiplexers **406** mix several channels at different wavelengths and output the wavelengths on the same light beam. In this aspect, the multiplexers **406** can be well-known passive combiners or selective combiners. In another aspect, the multiplexers **406** are optical time division multiplexers (OTDM), or high density wavelength division multiplexers (HDWDM). Alternatively, multiplexers **406** can be implemented using coherent multi-channel heterodyne or homodyne detection techniques. In fact, any type of optical combiner that can perform the function of combining the channels, such as fused filter couplers or Soliton multiplexers, also can be used to implement the multiplexers **406**. Of course, the invention is not limited by the particular type of multiplexing. For example, the channels can be combined into the light cone **106** using frequency, polarization, spatial position, polarity, space, algebraic transform methods, etc. An embodiment of the multiplexers **406** uses a dense wavelength division multiplexer (DWDM) to select channels at International Telecommunications Union (ITU) standards for the 1530nm-1560nm range (approximately 0.8nm separation between channels).

The power amplifiers **408** may receive and amplify one or more wavelengths that will be present in the light cone **106**. The power amplifiers **408** tolerate optical signals of many formats (or modulation schemes, such as polarity shift keying or amplitude shift keying) or bit rate (up to many Gbps), *e.g.*, the power amplifiers **408** are transparent. In one embodiment of the invention, one geographic locality contains three central network stations. The signals from each of these central network stations are divided into 36 sectors. Each sector is capable of carrying up to eight channels at 100 Mbps to 10 Gbps each, with an

overall local geographic capacity of up to 8.650 terabits per second (Tbps) (*e.g.*, 3 stations x 36 sectors x 8 channels x 10 Gbps.) In an embodiment, the power amplifiers are erbium doped fiber optic amplifiers (EDFA), that amplify one or more wavelengths simultaneously, available from JDS Fitel Corporation in Nepean, Ontario, Canada.

Figure 5 is a block diagram of illustrative user downlink signal processor **304** components. The embodiment user downlink signal processor **304** includes light cone detectors **502**, user demodulators **504**, user demultiplexers **506**, and user decoders **508**, which detect and separate data from the carrier in the light cone **106** after it is received from free space by the user antenna **302**.

The light cone detectors **502** detect and focus the light cone **106** onto a photodetector (not shown). The light cone detectors **502** may include a concentrator (not shown) which concentrates the light cone **106** and focuses it without loss. After detecting and focusing, the data on the light cone **106** is amplified with a preamplifier (not shown), converted to serial form with a serializer (not shown), and protocol converted using a protocol converter (not shown). The preamplifier, serializer, and protocol converter are available in a G-NIC network interface card manufactured by Packet Engines, as described above with reference to the modulators **404**. In this embodiment, the protocol converter can either convert the modulation of the light cone **106** to a Gigabit Ethernet format or reduce it down to a 100 Mbit format. The detectors also include well-known pattern masks, such as diffraction gratings. The light cone detectors **502** output the light cone **106** to the user demodulators **504**. Illustrative light cone detectors **502** are implemented in PIN diode in an off-the-shelf 1550nm transceiver unit manufactured by MRV Communications located at 20415 Nordhoff Street, Chatsworth, California 91311.

The user demodulators **504** demodulate the carrier using well-known demodulation techniques compatible with the modulation schemes used by the modulators **404**. For example, in one embodiment, the user demodulators **504** are implemented in the Ethernet PCI cards.

The user demultiplexers **506** separate the wavelengths back into frequency-separated independent optical channels using techniques compatible with the multiplexers **406**. The demultiplexers **506** can be well-known passive splitters or selective splitters.

The user decoders **508** convert data from the representation of the data established by the encoders **402**. For example, the user decoders **508** decodes data and control signals from a high-speed data stream. An embodiment is implemented in a MAC chip on Packet Engines' G-NIC. Of course, the user decoders **508** can be implemented in any Ethernet card, switch, or repeater with the same encoding capabilities. The user decoders **508** output decoded data to the user input/output interface **306**, which then makes the data available to the peripheral networks **105**.

Any or all of the components in the embodiments in Figures 2 and 4 or Figures 3 and 5 can be implemented on a single card, respectively. In one embodiment of the invention, the components in Figures 2 and 4 are implemented in a single card from Packet Engines. Similarly, the components in Figures 3 and 5 are implemented in a single card from Packet Engines. Of course, those skilled in the relevant art will appreciate that a particular physical location for the components in Figures 2 and 4 or Figures 3 and 5, respectively, is not essential to practice the embodiment.

Downlink Transmission and Reception Operation

Figure 6 is a flow diagram of a downlink data transmission and reception process **600** performed by the central network **102** downlink transmission components, the user network **104** downlink reception components, and the peripheral networks **105**. The process **600** starts at step **602**, where control immediately passes to step **604**. In step **604**, the central router/switcher **204** receives data from the peripheral networks **105** designated for recipients in the user networks **104** or other central networks **102**.

In step **606**, the central router/switcher **204** routes the data to the central downlink signal processor **206**, where in step **608**, the data is processed for transmission using the encoders **402**, modulators **404**, multiplexers **406**, and power amplifiers **408**. Following encoding, modulation, multiplexing, and amplifying, in step **610**, the central transmit antenna **208** transmits the data into free space on the light cone **106**.

In step **612**, the user antenna **302** receives the light cone **106**. The user downlink signal processor **304** processes the light cone **106** to remove the data from the carrier, and to separate out one or more of the channels. In step **614**, the user input/output interface **306** sends that data to the peripheral networks **105**, as indicated by step **616** and/or to the user equipment and devices **308**, indicated by step **618**, as appropriate. Following steps **616** and **618**, operation of the process **600** is complete, as indicated by step **620**.

Uplink Transmission and Reception Structure

Figure 7 is a block diagram of illustrative user network **104** uplink transmission components. The peripheral network **105** sends data for transmission to the central networks **102** via the user input/output interface **306** and/or the user equipment and devices **308** and sends it to a user uplink signal processor **702**. The user uplink signal processor **702** outputs the data to the user antenna **302** for transmission into free space on the collimated light beam **108**, which is received by the central networks **102**. The user uplink signal processor **702** is described more fully below with reference to Figure 9.

Figure 8 is a block diagram of illustrative central networks **102** uplink reception components. A central receive antenna **802** receives data transmitted from the user networks **104**, processes the data using a central uplink signal processor **804**, and routes the data to the peripheral networks **105** via the central router/switcher **204**. The central system controller **210** controls the operation of the central router/switcher **204** and the central uplink signal

processor **804**. The central uplink signal processor **804** is described more fully below with reference to Figure 10.

Figure 9 is a block diagram of illustrative user uplink signal processor **702** components. The illustrative user uplink signal processor **702** includes user multiplexers **902**, user modulators **904**, and user optical transmitters **906**. The multiplexers **902** operate similarly to the multiplexers **406** in the central downlink signal processor **206**, in that the multiplexers **902** can combine channels using WDM, OTDM, HDWDM, coherent multi-channel heterodyne or homodyne detection techniques. fused filter couplers, or Soliton multiplexers, for example.

The user modulators **904** operate similarly to the modulators **404** of the central downlink signal processor **206**. For example, the user modulators **904** can implement several types of well-known modulation schemes used for communications. In one aspect of the invention, the user modulators **904** are implemented in well-known Ethernet PCI cards whose input and output are via optical fiber. The user optical transmitters **906** perform well-known optical signal processing on the data prior to output to the user antenna **302**. An illustrative optical transmitter **906** includes a laser, an amplifier, and a telescope. This embodiment uses a telescope manufactured by Meade in Irvine, California, whose eyepiece has been adapted to allow a fiber optic element to be inserted into the eyepiece (so that the laser light can be sent into the telescope, and thus, transmitted into free space).

The output of the user optical transmitters **906** is sent to the user antenna **302**, which transmits the multiplexed and modulated data as the collimated light beam **108** to the central networks **102**. The central networks **102** receive the collimated light beam **108**, process it using the central uplink signal processor **804**, and send the data to any of the peripheral networks **105**.

Figure 10 is a block diagram of illustrative central network **102** uplink components. As Figure 10 shows, the central receive antenna **802** receives the collimated light beams **108** from free space. The central receive

antenna **802** receives the collimated light beams **108** using an optical receiving antenna, which, in one embodiment of the invention, uses holographic optical elements.

The central uplink signal processor **804** includes collimated beam detectors **1002**, central demodulators **1004**, and central demultiplexers **1006**. The collimated beam detectors **1002** detect and focus the collimated light beam **108** and provide spatial offsets to spatially separate and separately detect each collimated light beam **108** whether on identical or differing wavelengths. The collimated beam detectors **1002** can be similar to a two-dimensional array of photodetectors, each receiving a collimated light beam **108** from a different user network **104** or a lower level node. The collimated beam detectors **1002** output signals corresponding to the different collimated light beams **108**. The central receive antenna **802** outputs the signals corresponding to the different received collimated light beams **108** to the central demodulators **1004**. In one embodiment, the collimated beam detectors **1002** focus the collimated light beam **108** onto a 1500nm detector that detects data at rates in excess of 10 Mbps. Such detector is available from MRV Communications.

The central demodulators **1004** demodulate the carrier using well-known demodulation techniques compatible with the modulation schemes used by the user modulators **904**. For example, in one embodiment, the user demodulators **1004** are implemented in well-known Ethernet PCI cards.

The central demultiplexers **1006** further separate the wavelengths back into spatially independent optical channels using techniques compatible with the user multiplexers **902**. As such, the central demultiplexers **1006** can be well-known passive splitters or selective splitters. The central demultiplexers **1006** output data to the central router/switcher **204**, which then makes the data available to the peripheral networks **105**.

Uplink Transmission and Reception Operation

Figure 11 is a flow diagram of an uplink data transmission reception process **1100** performed by the central network **102** uplink transmission components, the user network **104** uplink reception components, and the peripheral networks **105**. The process **1100** starts at step **1102**, where control immediately passes to step **1104**. In step **1104**, the user input/output interface **306** receives data from the peripheral networks **105** and routes the data to the user uplink signal processor **702**.

In step **1106**. the user uplink signal processor **702** processes the data for transmission using the user multiplexers **902**. user modulators **904**, and user optical transmitters **906**. In step **1108**, the user antenna **302** transmits the data into free space on the collimated light beam **108** into free space. In step **1110**, the central receive antenna **802** receives the collimated light beam **108** from free space.

In step **1112**, the central uplink signal processor **804** invokes steps **352** through **358** of the user system controller **310** receive function **350** (*see, e.g.*, Figure 3B) and processes the collimated light beam **108** to remove the data from the carrier, and to separate out one or more of the channels.

In step **1114**, the central router/switcher **204** sends that data to the peripheral networks **105**, as indicated by step **1114** and/or to other central networks **102**, indicated by step **1116**, as appropriate. Following steps **1114** and **1116**, operation of the process **1100** is complete, as indicated by step **1118**.

It is noted that it can be less expensive to transmit from the user networks **104** to the central network **102** using the collimated light beam **108** as opposed to a shaped and diverging light cone **106**, as is transmitted from the central network **102** to the user networks **104**. For example, the collimated light beams **108** require less power. Moreover, transmitting using the collimated light beams **108** ensures that there is little interference between bidirectional light transmissions between the central networks **102** and the user networks **104**.

Recall that the communication system **100** (*see, e.g.*, Figure 1) also supports conventional methods of data communication. Accordingly, the communication network **100** can communicate at data rates commensurate with the medium of communication. For example, the communication system **100** can transmit into free space at one data rate and receive via telephone lines at a different (*e.g.*, lower) data rate.

Data Packet Structure

As described above, the communication system **100** uses packet-switching technology, in which data is divided into individual data packets before transmission and routed through different network elements and may therefore arrive at different times or out of sequence. If received out of sequence, the individual data packets are reassembled at the intended destination.

Figure 12 illustrates a data packet **1200** suitable for use with the communication system **100**. The data packet **1200** includes a payload **1202**, which typically is the data content. For example, the data content can be stock quotes, video/audio for a teleconference, etc. Those skilled in the art will appreciate that the particular payload may vary according to the application and may include information needed to facilitate reassembly of the data packets into the original data sequence.

The data packet **1200** also includes a header **1204**. The header **1204** typically includes a destination address **1206** that specifies the destination network element (or recipient) to which the data packet **1200** is to be routed. That is, the address **1206** specifies which central network **102**, user network **104**, or peripheral network **105**, or their lower level nodes is the designated recipient of the particular data packet **1200**. When the recipients recognize their particular address **1206** in the data packet **1200**, the recipients accept the payload **1202** appended to the address **1206**.

The data packet **1200** also includes a cyclical redundancy check (CRC) **1208**, that is used to detect errors in the transmission of the data packet

1200. Other forms of error detection and correction may be used in place of, or in addition to, the CRC **1208**. The data packet **1200** may also include error correction data under any conventional error correction method. The data packet **1200** also includes a miscellaneous portion **1210** for miscellaneous control or data information, such as for multicasting or broadcasting sessions. An illustrative data packet **1200** is a SONET data packet structure. An alternative is a standard Internet Protocol (IP) data packet, (*e.g.*, IPv.4 (IPv.6) data packets with IEEE Ethernet 802.3 framing).

Sectorization

Recall that in one embodiment, data is sent from the central networks **102** to the user networks **104** using the light cones **106**, and that the light cones **106** are shaped and diverging coherent light beams. Several shaped and diverging coherent light cones **106** are radiated in the substantially circular radiation pattern that illuminates any or all parts of the area surrounding the central networks **102,** much like a theatrical spotlight illuminates a stage. Parts of the illuminated areas can be emphasized, or made "brighter" than others, in order to deliver more signal strength to chosen areas. As is the case with the theatrical spotlight, the light cones **106** can be configured into any shape. The radiation pattern radii can be anywhere from one quarter meter to over three kilometers.

Each central network **102** optically shapes the laser radiation patterns into the narrow radial sectors containing elevation sectors into which the wavelengths of infrared laser lights are transmitted. In one embodiment, the central downlink signal processor **206** shapes the laser beam into the desired radiation pattern, with radial (or horizontal) sectors and/or elevation (or vertical) sectors further divided into several channels. Each channel is allocated particular wavelengths. A user can be assigned a wavelength such that the central networks **102** transmit a high-speed data stream to each user or group of users on the assigned wavelength. Each vertical sector and each horizontal sector may have

one or more channels of different wavelengths. Each of the channels may carry at least 10 Gbps of data. This arrangement accommodates a data transmitting capacity in excess of 20 Tbps and can service thousands of users.

Figure 13 illustrates an illustrative transmission point **1301** with sectorization **1300**. According to this embodiment, there are several horizontal subsectors, as represented by subsectors **1302a**, **1302b** and **1302c**. Each sector may have vertical subsectors, as represented by subsectors **1306a** and **1306b**. Each vertical or horizontal subsector may be further divided into another subsector. Each horizontal subsector **1302a-c** and/or vertical subsector **1306a-c** can have one or more wavelength channels (not shown).

When the communication system **100** communicates using the transmission point **1301** with the sectorization pattern **1300,** the address in the data packet **1200** specifies the appropriate sector **1302** and wavelength channel.

It should be noted that the highly controllable shaped beams make wavelength (or frequency) reuse a non-issue using the communication system **100**. The sectors in the communication system **100** are strictly spatially separated, and so any channel can be used in any sector. This spatial reuse technique provides distinct advantages over common non-optical systems. Conventional frequency reuse schemes were necessary because of radiation pattern side lobe interference caused by well-known right phrasing. Implementation of sectorization and shaped and diverging coherent light beams **106** avoids side lobe interference problems and, thus, avoids the need for frequency-reuse schemes. To accomplish this, the central transmit antennas **208** use central geometric antennas that are very large in terms of operating wavelength (*e.g.*, approximately eighty times the wavelength). Conversely, conventional radio antennas are approximately the same size as the carrier wavelength, so they cannot use geometric optics for their transmission sectors.

The transmission point **1301** with the sectorization pattern **1300** can generate several types of "footprints," as defined herein as an area of coverage projected onto the buildings housing the user networks **104** by the beam

radiated from the transmission point **1301**. In an embodiment, the transmission point **1301** has shaped sectorization designed to project a roughly circular footprint on the buildings housing the user networks **104**.

Of course, the invention is not limited by the shape of the footprints. Figure 14 illustrates examples of various suitable footprints **1402a-f** generated by the central transmit antennas **208**. While, in some cases, only one central transmit antenna **208** is illustrated per set of light cones **106** transmitted, it is to be understood that, for example, the central transmit antenna **208a** includes several telescopes, each capable of generating a uniquely shaped radiation pattern. For example, as one telescope of the central transmit antenna **208c** generates a light cone **106d** which produces a substantially circular footprint **1402d**, another telescope of the central transmit antenna **208c** generates a light cone (not shown) which produces a substantially heptagonal footprints **1402c**.

Other footprints include elliptical, hexagonal, donut-shaped, square, etc. For example, referring back to Figure 13, the subsector **1302a** would generate an elliptical footprint. The subsector **1306a** produces a hexagonal footprint. The subsector **1306b** generates a donut-shaped footprint.

One purpose for overlapping radiation patterns is to deliver data at different data rates or capacities to the same building. Of course, the particular radiation pattern used is determined by a number of factors, including the size and shape of the building that houses the user networks, for example, that ensure that the power in the optical signal is effectively utilized.

The communication system **100** also can include an optical repeater **1404**, which receives, reconstructs, and amplifies either one way or bidirectionally the light cones **106** and retransmits them to the user networks **104**. The optical repeater **1404** compensates for dead spots in the transmitting radiation patterns. The optical repeater **1404** thus acts as an extension between central networks **102**. The optical repeater **1404**, while depicted as a single element, may contain multiple receiver-transmitter pairs that detect, reconstruct,

amplify, and retransmit the light cones **106** under the components discussed above with respect to Figures 2-6.

Figure 15 shows an illustrative topography **1500** surrounding the central networks **102**, by the sectorization pattern **1300**. The embodiment depicted in the topography **1500** includes three hexagonal light propagation patterns **1502a**, **1502b**, and **1502c**. In this embodiment, each sectorization pattern **1300** has 36 sectors, where one sector in each sectorization pattern **1300** is represented by the sectors $\mathbf{1502a_1}$, $\mathbf{1502b_1}$, and $\mathbf{1502c_1}$, respectively. An alternative embodiment has 60 radial sectors, each with six degrees of azimuth, and five elevation sectors, each with eight channels accommodating a data rate from 10 Mbps to 10 Gbps. Still another embodiment divides a radiation pattern into 120 three-degree sectors, with each sector delivering 10 Mbps to 10 Gbps to the user networks **104**.

Figure 15 also depicts several central networks **102** interconnected by ultra-wide bandwidth optical backbone links **1510**. The optical backbone links **1510** also allow interconnection with Internet POPs, major carriers, the PSTN, or other peripheral networks **105**.

The systems, methods, and interconnected devices for networked, high-speed bi-directional data communication through free space described herein are particularly suitable for use in foggy weather conditions, where optical signals are susceptible to attenuation. A study in London, England of point-to-point laser communication produced data on reliability that, when combined with a historical database, produced a weather database with forty years of data collected on an hourly basis. With this kind of information, the parameters of the communication system **100** can be modified to compensate for certain atmospheric conditions. For example, the power output of the central transmit antennas **208** and/or the user antennas **302**, radii of the cells, sensitivity of the detectors and/or the data rate can be increased or decreased as appropriate. Similarly, the size of the antennas can be adjusted to compensate for any anticipated attenuation of the signal.

The coverage area of the radiation pattern generated by the central transmit antenna **208** also can be predetermined by design to anticipate atmospheric conditions. For example, in the city of Seattle, Washington which is known for foggy conditions typically causing strong attenuation, the radiation patterns can be reduced to one quarter kilometer, as opposed to the two kilometer radiation patterns appropriate for sunny locations.

Other suitable modifications include changing the shape of the light cones **106**, changing the tint of the windows through which the light beams/light cones are transmitted, changing the optical amplifier strengths, etc.

Broadcast and Multicast Operation

Recall that the communication system **100** broadcasts and multicasts data from the central networks **102**. During broadcast operations, the data is transmitted from any one of the central networks **102** or their lower level nodes to all user networks **104** and/or all peripheral networks **105** and/or their lower level nodes, for example. Any well-known broadcast addressing scheme is suitable for implementing this embodiment.

During point-to-multipoint multicast communication, selected user networks **104**, peripheral networks **105**, and/or their lower level nodes receive data. This embodiment is ideal in situations where identical data content is desired to be transmitted to a particular group of user networks **104** and/or peripheral networks **105** substantially simultaneously (*e.g.*, during video teleconferences).

In this embodiment, the miscellaneous portion **1210** of the data packet **1200**, depicted in Figure 12, includes a multicast session identifier (not shown) that identifies a multicast session and a set of users that are the recipients of the transmission during the particular multicast session. The content of the transmission that one member of a multicast session group receives is substantially the same as the high-speed data that another member of the multicast session group receives during a particular multicast session.

Each multicast session identifier is associated with a set of unique addresses. There is a unique address for each recipient of the multicasted data. The central network **102** transmits the multicast session identifiers to the recipients, which use the association to determine the unique address for each of the recipients associated with the set of unique addresses. The central network **102** adds the unique addresses for the recipients to each data packet **1200** received from the other interconnected networks prior to transmitting the received data packet **1200** to the specified set of recipients.

Each central network **102** also may include a plurality of multicast session identifier translation tables to translate multicast session identifiers into unique addresses for the subscribers. There may be one or more multicast sessions identified by multicast session identifiers. Each of the multicast session identifiers is associated with a set of unique addresses representing a set of users. The central network **102** includes at least one translation table to correlate the multisession identifiers with each set of unique addresses for the set of selected recipients.

Table 1 is an example of a multicast session identifier table suitable for use with one embodiment of the invention. Table 1 lists example multicast sessions (1 through 4), functional group identifiers (A through D) for the functional groups associated with a particular multicast session, sets of addresses for the particular recipients in the particular functional group, and recipients associated with the unique addresses designated to receive transmissions during the particular multicast session. Note that the multicast sessions may have overlapping recipients such that one recipient may be included in the multicast session "1" as well as in the multicast session "2." Note that the recipients are designated **104a** through **104d** to represent either several user networks **104** or several of their lower level nodes.

Table 1

Multicast Session	Functional Group ID	Unique Addresses	Recipients
1	A	0112.3456.7890 0223.4567.8901 0334.5678.9012 0445.6789.0123	104a 104b 104c 104d
2	B	0445.6789.0123 0223.4567.8901 0334.5678.9012	104d 104b 104c
3	C	0445.6789.0123 0112.3456.7890	104d 104a
4	D	0445.6789.0123 0334.5678.9012	104d 104c

Figure 16 is a flowchart showing an illustrative multicast process **1600**. The multicast process **1600** starts at step **1602**, where control immediately passes to step **1604**. In step **1604**, one of the peripheral networks **105** transmits high-speed data and a multicast session identifier to the central network **102**. For example, according to Table 1, during the first multicast session, one of the peripheral networks **105** transmits the functional group identifier "A" to the central network **102**.

In step **1606**, the central network **102** receives the high-speed data and the multicast session identifier. In step **1608**, the central network **102** determines the functional group associated with the multicast session by looking in its translation table. In step **1610**, the central network **102** determines the set of recipients in the functional group.

In step **1612**, the central network **102** determines the unique address of each recipient in the set of recipients in the functional group. For example, the central network **102** looks in its multicast session identifier translation table to determine the unique address for the sets of recipients associated with the functional group identifier "A." In step **1614**, the central network **102** adds the unique address for the sets of recipients to the high-speed data received from the central network **102** and transmits the resulting high-speed data to the recipients **104a-d**. Once the high-speed data has been transmitted

from the central network **102** to the recipients **104a-d**, the multicast process **1600** ends, as indicated by step **1616**.

It is noted that the multiplexing and demultiplexing schemes used by the central networks **102** differ from the multiplexing and demultiplexing schemes used by the user networks **104** in that the central networks' **102** multiplexing and demultiplexing schemes have additional levels of address translation to accommodate routing of incoming IP addresses to the appropriate addressees. The additional routing is implemented in the central router/switcher **204**.

All of the optics described herein can be enclosed in a "black box," such as a Faraday cage, to isolate the optical components from outside interference such as extraneous optical frequencies. Enclosing the optics in a black box is less expensive and simpler than conventional methods for eliminating outside interference.

Recall that the central router/switcher **204** connects the central network **102** to the peripheral networks **105** and to the user networks **104**, enabling data to be exchanged between them. Recall further that the central router/switcher **204** supports NICs implemented in a G-NIC Network Interface Card available from Packet Engines. Figure 17 shows an illustrative central router/switcher **204** implemented on the G-NIC Network Interface Card.

The central router/switcher **204** in this embodiment includes a gigabit uplink port **1702** and up to two server ports: an optional gigabit server port **1704** and a 10/100 Ethernet server port **1706**. The central router/switcher **204** also includes a glue logic and memory control processor **1707**. The gigabit uplink port **1702** receives data packets **1200** on its input and sends the data packets **1200** to the output of whichever server port is active. At the same time, the central router/switcher **204** sends any data packets **1200** received on an input of the active server port to the output of the gigabit up link port **1702**.

It is noted that all data packets **1200** coming from either server port **1704**, **1706** will be sent to the gigabit uplink port **1702**, but the data packets **1200**

coming from the gigabit uplink port **1702** destined for either server port **1704**, **1706** will be filtered by the glue logic and memory control processor **1707**. That is, only the data packets **1200** meeting the filter requirements will be sent to the appropriate server port **1704**, **1706**. At a minimum, the gigabit uplink port **1702** filters received data packets **1200** by accepting only the data packets **1200** destined for a particular Ethernet address. In this embodiment, the gigabit uplink port **1702** also accept broadcast data packets and multicast data packets. In one embodiment, filtering may be performed by a host computer system under the purview of a user network **104**.

The central router/switcher **204** in another embodiment is connected from one of the server ports directly to a matching port on a host computer system located at a user network **104**. In this embodiment, if the gigabit uplink port **1702** uses the same Ethernet address as the port on the host computer system, the central router/switcher **204** supports only that host on its gigabit uplink port **1702**. This is because the Ethernet address of the host computer system is programmed into the central router/switcher **204**.

In another embodiment, the central router/switcher **204** "auto-discovers" its Ethernet address from the data packets **1200** seen on the server ports. Alternatively, central router/switcher **204** is preprogrammed with the same Ethernet address as an Ethernet card assigned to the host computer system.

Some Additional Features

The communication system **100** increases both the transmit and receive communication capacity of conventional communication systems. The greater capacity is important to note because standard telephone lines are being pushed to their limit and can provide only approximately 60 Kbps of data network connection. Other network alternatives have been developed but have their limitations as well. For example, ISDN, once thought to be the wide area networking solution of choice, is limited to 128 Kbps. The newly touted ADSL services are limited to eight Mbps and are asymmetric (fast in only one

direction—the downlink). Existing personal computers (PCs) have the ability to network locally at over 100 Mbps, leaving these wide area network technologies extremely inadequate.

The most publicized attempt to break the bandwidth bottleneck incorporates satellites in low-Earth orbits (LEO). These satellite networks can obtain data down-link rates from 1.5-28 Mbps. The cost to deploy these systems, however, ranges into billions of dollars and requires years to deploy.

Fiber optic and LMDS are also available and planned technologies in the telecommunication market. While LMDS is thought to require only 25 percent of the capital cost of deploying optical fiber, there appears to be an upper limit from four to six Gbps of total traffic capacity per four kilometer wide cell, which places a significant limit on system growth. For example, in an area twice the size of downtown Seattle's business core, only 40 to 60 concurrent customers could have 100 Mbps access. In contrast, the optical communication system **100** can potentially serve up to thousands of such concurrent connections.

The communication system **100** may only require 30 percent of the capital cost of an LMDS (or approximately eight percent of fiber) without the two Gbps limitation of total capacity per cell. Recall that the communication system **100** has the ability to communicate at 2.5 Gbps duplex or 1.25 simplex per channel, and its overall capacity per system may be in excess of two Tbps. This capacity is 1,000 times higher than LMDS and translates to significantly lower infrastructure costs, and the ability to undercut competitors' pricing and/or outperform competitive offerings.

The communication system **100** accomplishes these staggering speeds/volumes by combining wireless, fiber, and networking concepts to form a unique network that has the ability to deliver terabits of information around the world in a very timely and cost-efficient manner.

The communication system **100** antennas are similar in size and shape to a small dish antenna of the type that can be found on many rooftops.

However, the antennas may be placed behind a window glass, making deployment much easier than rooftop-only installations.

While the technology that the communication system **100** implements allows for a radiation pattern radii well over three kilometers, for urban cores, however, the central networks **102** can be much smaller and dependent upon the geography of the region as well as the building size and building location. Moreover, as described above, the communication system **100** has a very advantageous channel re-use property, allowing significantly lower costs, significantly higher capacities, and greater bandwidth.

Using a very simple example, assume one central network **102** is sectored into 120 three-degree sectors, with each sector delivering 100 Mbps to 2.5 Gbps. In this very simple example, this single central network **102** has the ability to deliver 300 Gbps to a large number of users. With the addition of additional channels per sector, the data throughput increases significantly. By using eight channels per sector, the optical communication system **100** has the ability to effectively increase the data throughput on a single local central network **102** to 2.4 Tbps. Such a central network **102** could supply 100 Mbps service to 24,000 concurrent users. This far exceeds conventional communication systems. The only close competitor is LMDS, which currently is limited to about four Gbps per cell site.

Many of the components in the communication system **100** may be implemented using hardware, software, or a combination of hardware and software, and may be implemented in a computer system or other processing system. In aspects where the invention is implemented using hardware, the hardware components may be Application-Specific Integrated Circuits (ASICs), or a hardware state machine. In aspects that are implemented using software, the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.). That is, software may be available from a removable disk or from code downloaded on a

hard drive. Moreover, the software can include code stored in a module such as a Read-Only Memory (ROM), Programmable ROM (PROM), or any variation of an Erasable PROM (*e.g.*, EPROM, EEPROM, etc.).

According to one embodiment, the communication system **100** uses well-known Time Division Multiple Access (TDMA) techniques. In TDMA, each user network **104** is assigned one or more TDMA time slots based on the allocated wavelength (or data rate), and the networks communicate with each other during the designated TDMA time slots. When the communication system **100** uses TDMA technology, the communication system **100** can multiplex several user networks **104** on one TDMA channel, using a well-known diffraction grading (or pattern mask) to receive only certain bits from the data stream for each user network **104**.

A resource manager (not shown) coordinates assignments of TDMA time slots. The resource manager negotiates for a channel (*e.g.*, a time slot at a particular frequency).

Interconnection of the arrangement of the light cones **106** and the collimated light beams **108** may be done using standard Internet protocols, such as "open shortest path first" (OSPF), which is a link state routing algorithm that is used to calculate routes based on the number of routers, transmission speed, delays, and route costs. Interconnection of the light cones **106** and the collimated light beams **108** can also be accomplished using other well-known routing algorithms.

Figure 18 shows an alternative embodiment of the communication system **100**. This alternative embodiment uses a multi-access receiver/transmitter (MART) **1802** for both transmission and reception. The central network **102** is connected to the MART **1802** by a transmission link **1800**. The transmission link **1800** is a hardwire link, such as a telephone line or fiber optic cable, but it is also possible to use a wireless link (*e.g.*, radio frequency, laser light, etc.). Additionally, while Figure 18 depicts the central network **102**

and the MART **1802** as being separated, remote components, it is appreciated that the MART **1802** can be within the central network **102**.

The MART **1802** includes an array **1804** of central transmit antennas **208** and central receive antennas **802**. The central transmit antennas **208** in Figure 18 are coaxially located at the center of their respective central receive antennas **802**. Other modifications are possible. For instance, the central transmit antennas **208** may be located near (*e.g.*, separated from) their respective central receive antennas **802**, instead of being coaxially located. It is also possible to use the same optical device to transmit and receive if wavelength separation between the transmitted and received signals is adequate.

Downlink transmission from the central network **102** to the user network **104** and/or the peripheral network **105** uses a concept of splitting a single broadcast beam into several light cones **106**, with each light cone **106** having all of the information present in the single broadcast beam. First, one or more power amplifiers **408**, such as a 500 mW EDFA, in the MART **1802** splits the single broadcast beam received through the transmission link **1800** and provides the individual signals to respective central transmit antennas **208**. The central transmit antennas **208** then transmit the individual signals as light cones **106** to the user network **104** and/or the peripheral network **105**. The array **1804**, or the individual central transmit antennas **208** and central receive antennas **802**, can be mounted, for example, onto one or more gimbal structures to direct the transmitted light cones **106**. Available optics are used to focus and direct the light cones **106** as necessary.

The embodiment shown in Figure 18 allows one or more light cones **106** to be focused on particular receivers in the user network **104** or the peripheral network **105**. That is, instead of transmitting to an entire building, separate light cones **106** can be transmitted to particular receivers in the building. Further, the separate light cones **106** can have different power, such that light cones **106** having greater power are transmitted to receivers that are farther away or are behind darkly tinted windows, and light cones **106** having less power are

transmitted to closer-range receivers. Also, the MART **1802** can transmit to more than one building, such that some light cones **106** are transmitted to one building and other light cones **106** are transmitted to other buildings. By adjusting the power level of the transmission and pointing the central transmit antennas **208** in the appropriate direction, it is thus possible to "link" several buildings and at greater distances from the same MART **1802**. To maximize efficiency, a given power output of the power amplifier **408** can be apportioned between the various light cones **106**, such that light cones **106** requiring less power are reduced in power while the other light cones **106** requiring more power are correspondingly increased in power.

Further, the scope of transmission coverage of the MART **1802** is easily changed by adjusting the number of splits in the power amplifier **408**. A sector of up to a full hemisphere is possible by splitting a single broadcast signal with the power amplifier **408** and providing central transmit antennas **208** in each quadrant.

The MART **1802** can also receive collimated light beams **108** from the user network **104** and/or peripheral network **105**. A plurality of collimated light beams **108** transmitted from individual transmitters in the user network **104** and/or the peripheral network **105** are received by the central receive antennas **802** in the MART **1802**. Like the transmission from the MART **1802** described above, the uplink transmission of collimated light beams **108** from the user network **104** and/or the peripheral network **105** to the MART **1802** allows multiple signals to be linked at the MART **1802**.

Many possible design parameters can be used for the embodiment shown in Figure 18. For instance, a 12° sector can project a light cone **106** of 100 meters in diameter at a distance of 500 meters. A three mrad beam can project a light cone **106** having a diameter of 1.5 meters at a distance of 500 meters. Using the same transmit power and assuming zero losses during the split, a three mrad beam can be projected at each of 4,444 customers and have the same power density as the 12° sector. Alternatively, service can be provided to

100 customers, with a 16 dB of link margin for each. The increased link margin can be used to reduce the size and costs of each customer's receiver.

Although specific aspects of, and examples for the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention and can be made without deviating from the spirit and scope of the invention, as will be recognized by those skilled in the relevant art. For instance, although a laser has been described herein as generating the various light beams and light transmissions, other light-generating devices, such as light-emitting diodes (LEDs), can be used. Also, although the collimated light beams **108** are used in the network uplink components (*see, e.g.*, Figures 7-10) and the light cones **106** are used in the network downlink components (*see, e.g.*, Figures 2 and 3-5) in the embodiments described herein, it is to be appreciated that in some embodiments, the network uplink components can use the light cones **106** or the network downlink components can use the collimated light beams **108**. Further, several channels (*e.g.*, frequency domain) can be used in the uplink as well, with appropriate coordination between a user and a central node.

The teachings provided herein of embodiments of the invention can be applied to optical links made functional by any standard network interconnection. For example, the G-NIC Network Interface Card (*see. e.g.*, Figure 2) can be implemented in PCs. Further, one or more components or functions of the communication system **100** can be embodied in a computer network, computer-readable media (such as magnetic cassettes, digital video disks, CD-ROMs, Bernoulli cartridges, random access memories (RAM), ROMs, smart cards, etc.) and their associated devices. One or more components or functions of the communication system **100** can be embodied in computer-readable or computer-executable instructions such as program modules or macros executable by a microprocessor or by a computer. How to implement these types of features can be understood by one skilled in the art based on the detailed description provided herein.

These and other changes can be made to the invention in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the invention to the specific aspects disclosed in the specification and claims, but should be construed to include all optical communication systems that operate under the claims to provide, *inter alia*, high-speed optical data communication. Accordingly, the invention is not limited by the disclosure, but instead the scope of the invention is to be determined entirely by the following claims. which are to be construed in accordance with established doctrines of claim interpretation.

CLAIMS

What is claimed is:

1. A communication system, comprising:

a peripheral node configured to transmit at least one first information signal and configured to receive a second information signal;

at least one central node configured to receive the first information signal from the peripheral node and transmit the received first information signal through free space modulated on a first light beam, configured to transmit the second information signal to the peripheral node, and configured to receive at least one third information signal from free space modulated on a second light beam; and

at least one user node configured to receive the first light beam and demodulate the modulated first information signal from free space, and configured to transmit the third information signal through free space modulated on the second light beam.

2. The communication system of claim 1 wherein the first light beam comprises a shaped and diverging laser beam and the second light beam comprises a collimated light beam.

3. The communication system of claim 1 wherein the at least one central node includes:

a plurality of central nodes forming a central network, each central node configured to transmit a plurality of the first information signals modulated on shaped and diverging coherent light beams through free space; and

wherein the at least one user node includes a plurality of user nodes forming a user network, each user node configured to receive the plurality of first information signals modulated on shaped and diverging coherent light beams through free space. and

wherein the central nodes are configured to transmit to the user nodes in a node-to-node, node-to-multipoint, multipoint-to-node, or multipoint-to-multipoint manner.

4. A method for transmitting data between a central point and at least one user, the method comprising:

at the central point, modulating data and at least one user address on a light beam;

at the central point, transmitting the light beam through free space:

demodulating the light beam and retrieving the data and the at least one user address;

routing the data to the user according to the user address; and

transmitting data from the user to a central point.

5. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a shaped and diverging light beam.

6. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a shaped, diverging, and coherent light beam.

7. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a laser beam.

8. The method of claim 4, further comprising:

modulating the data and several user addresses on a light beam;

routing the data to the several user addresses; and

transmitting data from at least one of the users to a central point through free space or via at least one telephone line.

9. The method of claim 4, further comprising transmitting the light beam through free space to several user addresses in a point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint manner.

10. A communication system, comprising:

a central node configured to transmit through free space an information signal modulated on a diverging coherent light beam; and

a user node configured to receive from free space the diverging coherent light beam and automatically process the modulated informational signal, wherein the diverging coherent light beam, as received at the user node. has different dimensions diverging coherent light beam at the central node.

11. The communication system of claim 10, further comprising:

a plurality of central nodes each configured to transmit through free space a plurality of information signals modulated on a plurality of diverging light beams; and

a plurality of user nodes each configured to receive from free space the informational signals modulated on diverging light beams, wherein the central nodes are configured to transmit to the user nodes in a broadcast, simulcast. or multicast manner.

12. The communication system of claim 10 wherein the central node is configured to transmit through free space to the user node in one of a broadcast or multicast manner.

13. The communication system of claim 10, further comprising a peripheral node configured to transmit the information signal to the central node for modulation.

14. The communication system of claim 10, further comprising a common carrier, virtual node, or an area node configured to transmit the informational signal to the central node for modulation.

15. The communication system of claim 10 wherein the central node and the user node are interconnected using synchronous optical network (SONET) architectures.

16. The communication system of claim 10, further comprising a peripheral node, wherein the central node, user node, and peripheral node are interconnected using synchronous optical network (SONET) architectures.

17. The communication system of claim 10 wherein the central node and the user node are interconnected using gigabit Ethernet architectures.

18. The communication system of claim 10, further comprising a peripheral node, wherein the central node, user node, and peripheral node are interconnected using gigabit Ethernet architectures.

19. The communication system of claim 10 wherein the diverging light beam comprises a shaped, coherent infrared laser operating at a wavelength of approximately 1550nm.

20. The communication system of claim 10 wherein the diverging light beam comprises a shaped coherent infrared, near-infrared, or visible light laser beam.

21. The communication system of claim 10 wherein the light beam comprises a shaped and coherent diverging light beam.

22. The communication system of claim 10, further comprising a diffraction grating, beam shaping lens, or a holographic optical element.

23. The communication system of claim 10, further comprising a beam shaping optic that horizontally shapes the diverging light beam.

24. The communication system of claim 10, further comprising a beam shaping optic that vertically shapes the diverging light beam.

25. The communication system of claim 10 wherein the information signal further comprises at least one data packet having a header and a payload, the header specifying at least one of the user nodes and the payload comprising high-bandwidth data.

26. A communication system, comprising:

at least one user node configured to transmit an information signal through free space modulated on a light beam; and

a central node configured to receive the light beam from free space and to demodulate the information signal from the light beam, and to send the information signal to a peripheral node.

27. The communication system of claim 26 wherein the light beam comprises a collimated light beam.

28. The communication system of claim 26 wherein the light beam comprises a shaped and diverging light beam.

29. The communication system of claim 26 wherein the user node is configured to transmit the information signal modulated on a collimated laser beam

and the central node is configured to receive the information signal modulated on a collimated laser beam.

30. The communication system of claim 26 wherein the user node further comprises an antenna having a diffraction grating, beam shaping lens, or a holographic optical element.

31. The communication system of claim 26 wherein the light beam comprises a light beam in a substantially 1550 nm region of a light spectrum.

32. An apparatus configured to transmit an optical carrier through free space to a plurality of user nodes, comprising:

an input port configured to receive an information signal;

a radiant energy generator configured to generate an optical carrier:

a signal processor, coupled to the radiant energy generator and the input port, configured to process and combine the optical carrier with the information signal; and

an antenna, coupled to the signal processor, configured to produce a shaped and diverging radiant energy and to transmit the combined optical carrier and information signal on the shaped and diverging radiant energy into free space.

33. The communication system of claim 32, further comprising a multiplexer configured to combine several information signals from several wavelength channels into the optical carrier.

34. The communication system of claim 32, further comprising an optical time division multiplexer (OTDM), high density wavelength division multiplexers (HDWDM), a coherent multi-channel heterodyne detector, a coherent multi-channel homodyne detector, a fused filter coupler, a Soliton multiplexer, a frequency combiner, a polarity combiner, a spatial combiner, or an algebraic transform

combiner configured to combine several information signals from several channels into the optical carrier.

35. The communication system of claim 32, further comprising a power amplifier, an erbium-doped fiber amplifier, or a ytterbium-doped fiber amplifier configured to amplify the optical carrier.

36. The communication system of claim 32, further comprising an encoder configured to encode data and control signals into the information signal.

37. A method for transmitting and receiving data between a user point and one of a plurality of peripheral points via a central point, the method comprising:

at the user point, modulating data and at least one peripheral point address on a collimated light beam;

at the user point, transmitting the collimated light beam through free space to the central point;

at the central point, demodulating the collimated light beam and retrieving the data and the peripheral point address: and

routing the data to the peripheral point address.

38. The method of claim 37, further comprising modulating the data and the peripheral point address on a collimated laser beam.

39. The method of claim 37, further comprising:

modulating the data and several peripheral point address on several collimated light beams; and

routing the data to the several peripheral point addresses.

40. The method of claim 37, further comprising transmitting the light beams through free space to the peripheral points in a point-to-point, multipoint-to-point, or multipoint-to-multipoint manner.

41. A method for transmitting data, comprising:
combining several data channels into a data stream;
modulating the data stream on at least one diverging light beam;
transmitting the diverging light beam through free space;
demodulating the diverging light beam and retrieving the data stream; and
separating the several channels of data from the data stream.

42. The method of claim 41, further comprising:
modulating the data stream on a shaped and diverging light beam; and
routing the several data channels to several user devices.

43. The method of claim 41, further comprising modulating the data stream on a shaped, diverging, and coherent light beam.

44. The method of claim 41, further comprising modulating the data stream on at least two laser beams having different wavelengths transmitted over substantially a same diverging cone through free space.

45. The method of claim 41, further comprising transmitting the diverging light beam through free space to several users in a point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint manner.

46. The method of claim 41, further comprising encrypting data on several data channels.

47. The method of claim 41, further comprising encoding data on several data channels.

48. An apparatus for receiving an information signal, comprising:

an antenna configured to receive from free space an optical carrier having an information signal modulated on a shaped and diverging coherent light beam;

a signal processor, coupled to the antenna, configured to process and demodulate the shaped and diverging coherent light beam to separate the information signal from the optical carrier; and

an output port, coupled to the signal processor, configured to send the information signal to at least one device.

49. The communication system of claim 48 wherein the antenna includes at least one holographic optical element or a telescope.

50. The communication system of claim 48 wherein the signal processor includes at least one shaped and diverging coherent light beam detector, a demodulator, a demultiplexer, or a decoder.

51. The communication system of claim 48 wherein the interface is configured to send the informational signal to one of a signaling node management protocol (SNMP) device, a transmission control protocol (TCP) device, a gateway, a local area node, a bridge, a printer, a hard disk drive, a graphical display adapter, a television, a television set top box, telecommunication equipment, video conferencing equipment, audio/visual equipment, or home theater electronics.

52. A method of transmitting and receiving data, comprising:

receiving encoded data and a multicasting session identifier, the multicasting session identifier indicating a group of recipient user points selected from among a plurality of user nodes configured to receive the encoded data;

transmitting the encoded data and a multicasting session identifier on a shaped and diverging light beam via free space to the plurality of user nodes;

receiving the shaped and diverging light beam from free space; and

decoding the encoded data.

53. The method of claim 52, further comprising appending to the encoded data a group of unique user node addresses respectively representing the group of recipient user nodes.

54. The method of claim 52, further comprising modulating the encoded data and the group of unique user node addresses on a shaped and diverging light beam.

55. A data communication system, comprising:

a transmitter configured to transmit an informational signal through free space modulated on a shaped and diverging coherent light beam, wherein the coherent light beam is sufficiently divergent to be received by a plurality of spatially separated receivers; and

a set of receivers, selected from among the plurality of receivers, configured to receive the shaped and diverging coherent light beam from free space and decode the modulated informational signal.

56. The system of claim 55 wherein each receiver in the set of receivers has a unique receiver address and the transmitter is configured to add the unique receiver address to the informational signal before transmitting informational signal to the set of receivers.

57. The system of claim 55 wherein the transmitter is configured to transmit the informational signal using data packets having a multicasting session identifier associated with high-speed data and a set of selected receivers.

58. The system of claim 55, further comprising a storage device, coupled to the transmitter, configured to store a multicasting session identifier translation table to translate first and second multicasting session identifiers into unique receiver addresses of first and second sets of receivers, respectively.

59. A method for free space optical data communication, comprising:

receiving at an antenna, a shaped and diverging coherent light beam transmitted through free space, wherein the light beam has an information signal modulated thereon, and wherein a cross-sectional area of the received diverging coherent light beam as received at the antenna is substantially greater than an area of the antenna; and

demodulating and recovering the information signal from the shaped and diverging coherent light beam.

60. The method of claim 59 wherein the information signals comprises at least one video signal, audio signal or data signal.

61. The method of claim 59 wherein the high-speed information signals comprises at least one video signal at a first data rate, an audio signal at a second data rate, or a data signal at a third data rate.

62. A data communication system, comprising:

a transmission node having at least one radiant energy generator that generates information bearing radiant energy beams over several sectors,

wherein each subsector comprises a channel, and

wherein each channel operates at substantially the same wavelength.

63. The data communication system of claim 62 wherein the sectors comprise radial sectors.

64. The data communication system of claim 62 wherein the sectors comprise elevation sectors.

65. The data communication system of claim 62 wherein the sectors comprise radial sectors, wherein each sector includes at least two subsectors, and wherein the subsectors comprise elevation subsectors.

66. The data communication system of claim 62 wherein the sectors include at least one elliptically-shaped sector, hexagon-shaped sector, donut-shaped sector, elliptically-shaped subsector, hexagon-shaped subsector, or donut-shaped subsector.

67. The data communication system of claim 62 wherein each channel operates approximately at a 1550nm wavelength.

68. The data communication system of claim 62 wherein a first channel operates at a first wavelength and a second channel operates at a second wavelength.

69. The data communication system of claim 62 wherein the transmission node comprises a telescope.

70. A method of transmitting data comprising:

modulating at least one information signal on at least one carrier; and

substantially simultaneously transmitting the modulated information signal along a plurality of vertically differentiated sectors.

71. The method of transmitting data of claim 70, further comprising substantially simultaneously transmitting the modulated information signal along a plurality of horizontally differentiated sectors.

72. The method of transmitting data of claim 70, further comprising transmitting a plurality of channel wavelengths over each of the plurality of vertically differentiated sectors.

73. The method of transmitting data of claim 70 wherein at least two of the plurality of vertically differentiated sectors have differing cross-sectional beam shapes.

74. The method of transmitting data of claim 70 wherein each of the plurality of vertically differentiated sectors includes information modulated at the same wavelength.

75. The method of transmitting data of claim 70 wherein the at least one carrier comprises a plurality of diverging coherent light beams transmitted along the plurality of vertically differentiated sectors.

76. A communication system, comprising:

a central node configured to split an input signal into a plurality of substantially similar output signals;

a plurality of transmitters disposed in the central node to transmit the plurality of output signals to a user node as light signals; and

a plurality of receivers disposed in the central node to receive a plurality of user signals from the user node.

77. The system of claim 76 wherein the plurality of user signals comprise light signals.

78. The system of claim 76 wherein the plurality of output signals comprise a substantially same information content as the input signal.

79. An apparatus, comprising:

an amplifier having an input port to receive an input signal and operable to divide the input signal into a plurality of output signals;

a plurality of transmitters to transmit the plurality of output signals; and

a plurality of receivers associated with respective plurality of transmitters to receive user signals.

80. The apparatus of claim 79 wherein the output signals and user signals comprise light signals.

81. The apparatus of claim 79 wherein the plurality of output signals comprise a substantially same information content as the input signal.

82. A method of transmitting and receiving, the method comprising:

dividing an input signal into a plurality of output signals;

transmitting the plurality of output signals to a plurality of corresponding receivers of a user node; and

receiving a plurality of user signals transmitted from the user node light signals.

83. The method of claim 82 wherein transmitting the plurality of output signals comprises transmitting light signals.

84. The method of claim 82, further comprising providing each of the plurality of output signals with a substantially same information content as the input signal.

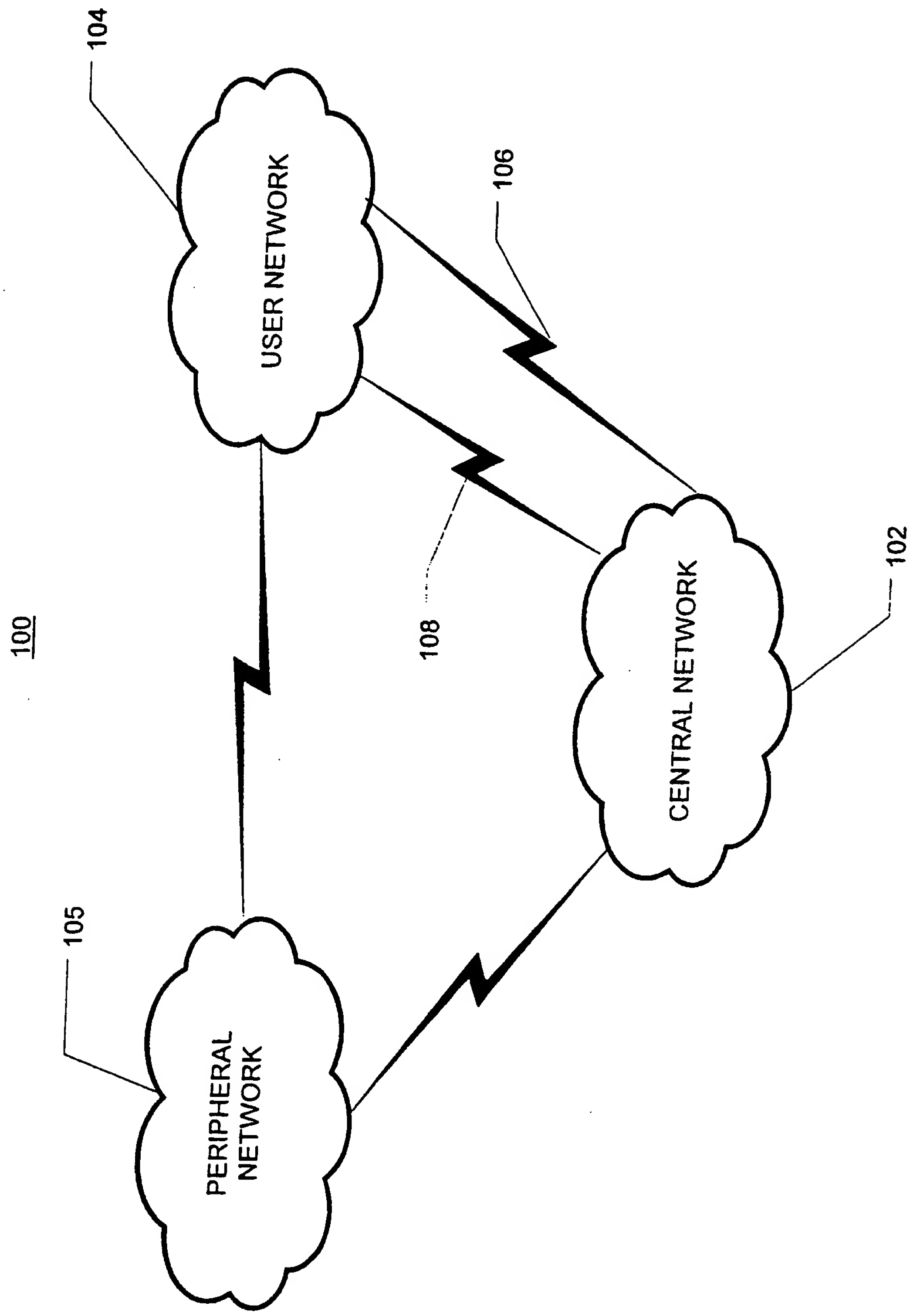

100
104
USER NETWORK
106
108
CENTRAL NETWORK
102
105
PERIPHERAL NETWORK

FIGURE 1A

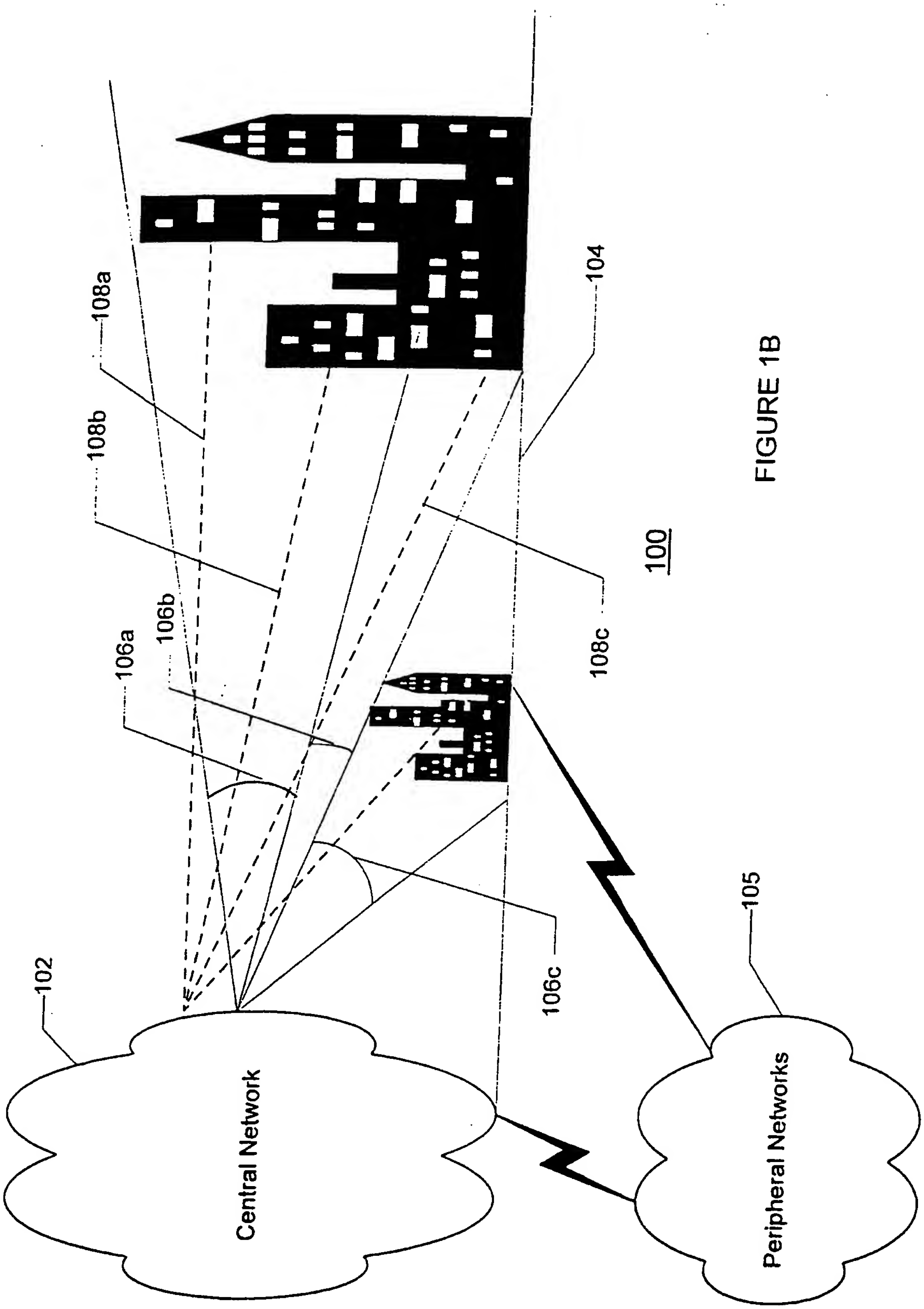

108a
108b
106a
106b
104
108c
100
102
106c
105
Central Network
Peripheral Networks

FIGURE 1B

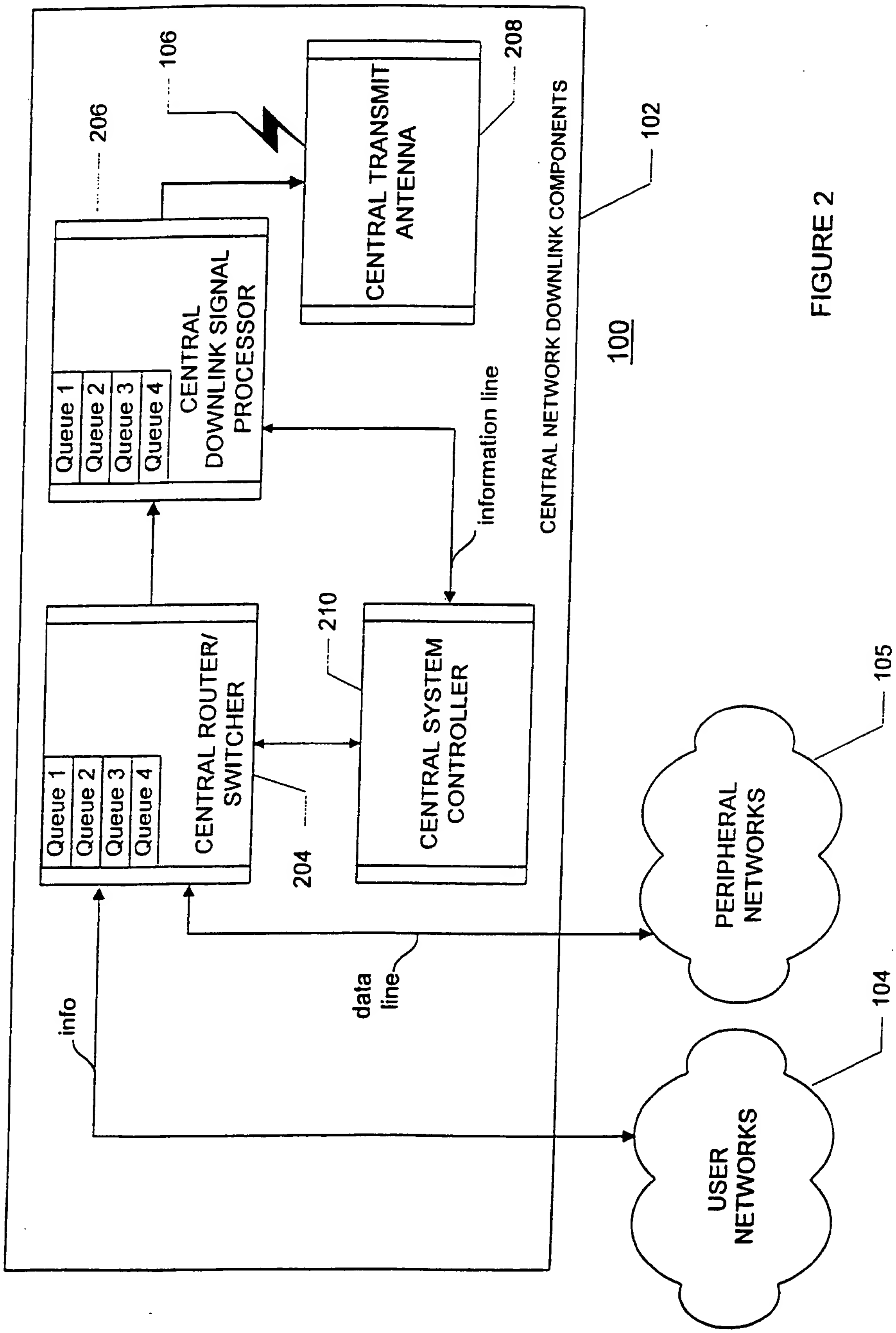

CENTRAL NETWORK DOWNLINK COMPONENTS
CENTRAL TRANSMIT ANTENNA
208
106
206
CENTRAL DOWNLINK SIGNAL PROCESSOR
Queue 1
Queue 2
Queue 3
Queue 4
information line
CENTRAL ROUTER/ SWITCHER
Queue 1
Queue 2
Queue 3
Queue 4
204
210
CENTRAL SYSTEM CONTROLLER
100
102
info
data line
PERIPHERAL NETWORKS
105
USER NETWORKS
104

FIGURE 2

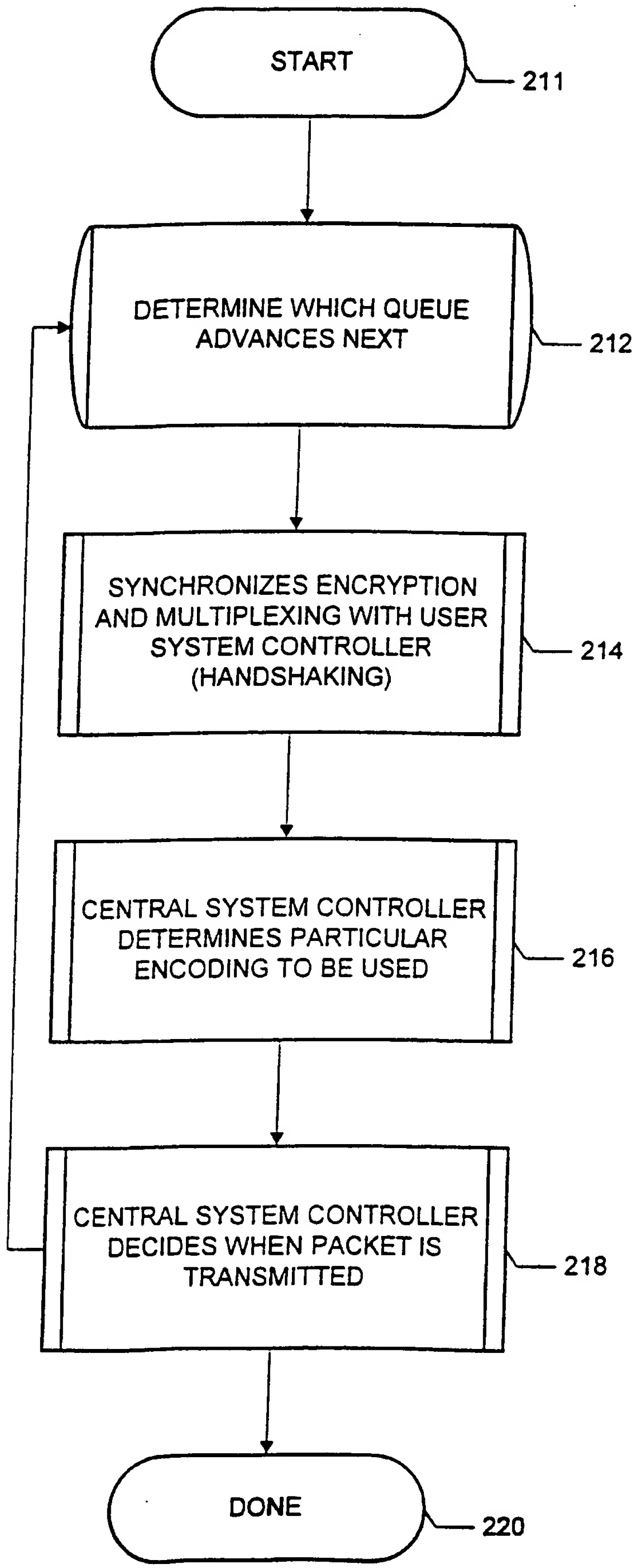
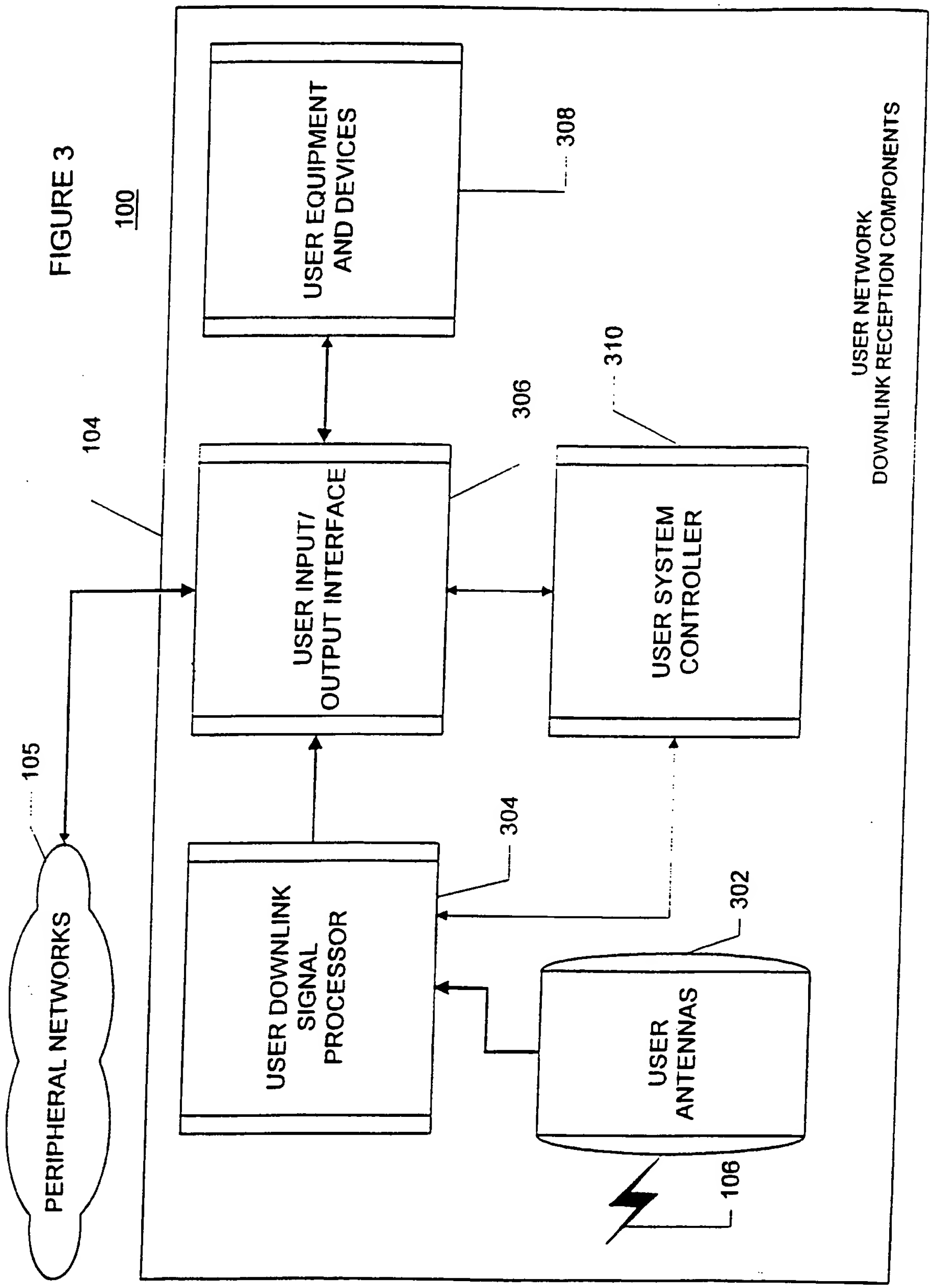


FIGURE 2A

CENTRAL SYSTEM CONTROLLER TRANSMIT FUNCTION 200

FIGURE 3

100


USER EQUIPMENT AND DEVICES
308
USER INPUT/ OUTPUT INTERFACE
306
USER SYSTEM CONTROLLER
310
USER DOWNLINK SIGNAL PROCESSOR
304
USER ANTENNAS
302
106
PERIPHERAL NETWORKS
105
104
USER NETWORK DOWNLINK RECEPTION COMPONENTS

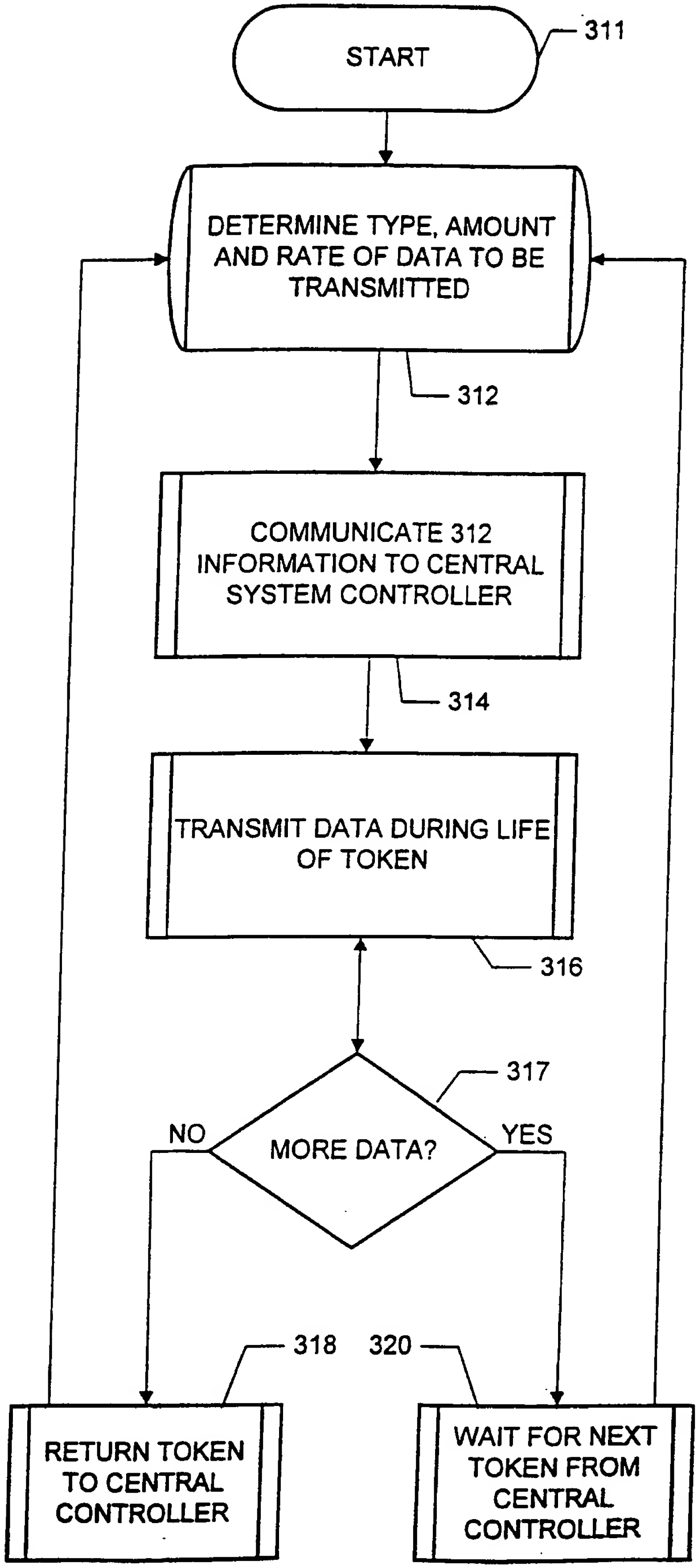


FIGURE 3A
USER SYSTEM CONTROLLER TRANSMIT FUNCTION WITH A TOKEN RING TIME DIVISION MULTIPLEXING (TDM) SYSTEM 300

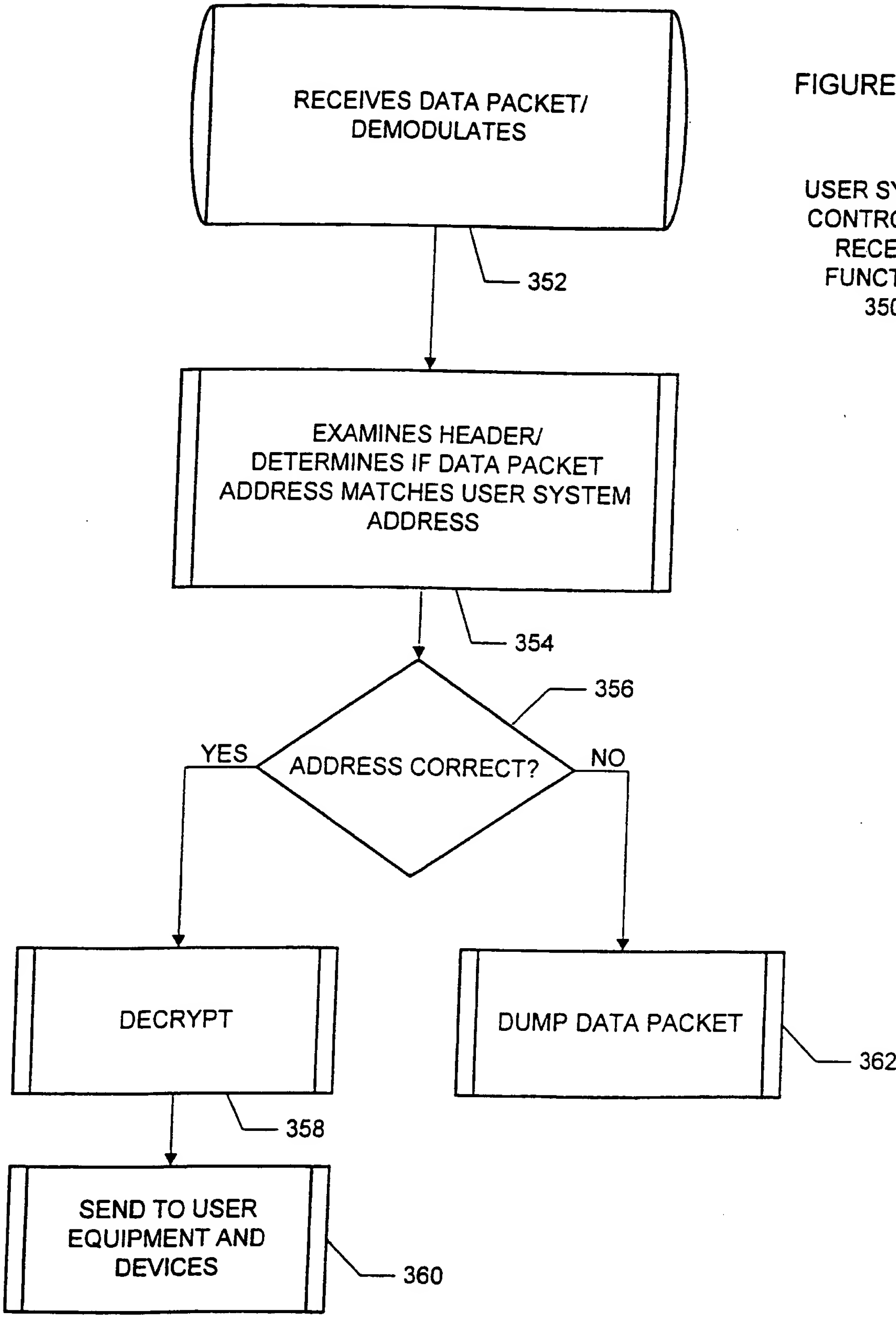


FIGURE 3B

USER SYSTEM
CONTROLLER
RECEIVE
FUNCTION
350

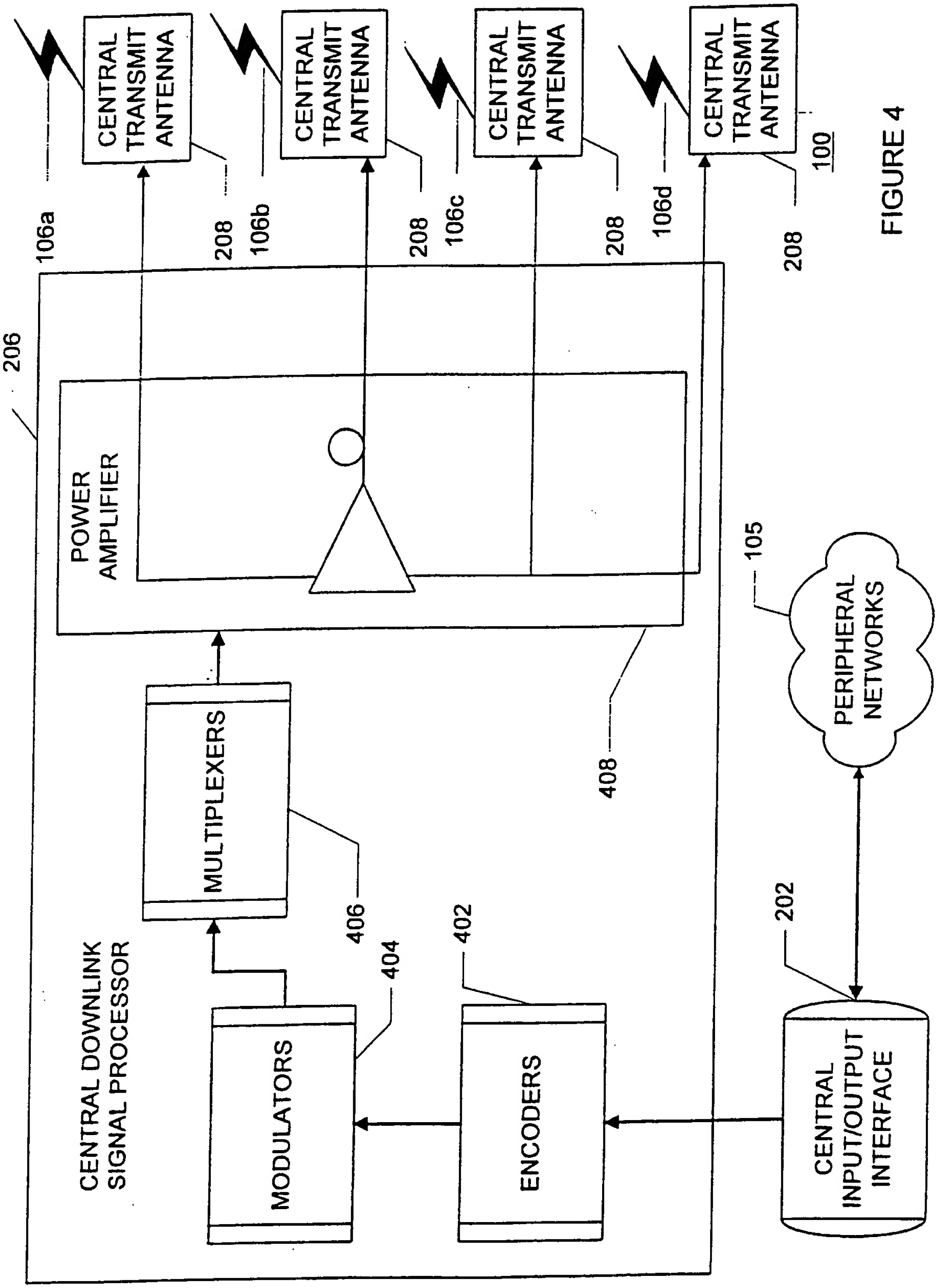

CENTRAL TRANSMIT ANTENNA
106a
208
CENTRAL TRANSMIT ANTENNA
106b
208
CENTRAL TRANSMIT ANTENNA
106c
208
CENTRAL TRANSMIT ANTENNA
106d
208
100
206
POWER AMPLIFIER
408
MULTIPLEXERS
406
CENTRAL DOWNLINK SIGNAL PROCESSOR
MODULATORS
404
ENCODERS
402
PERIPHERAL NETWORKS
105
CENTRAL INPUT/OUTPUT INTERFACE
202

FIGURE 4

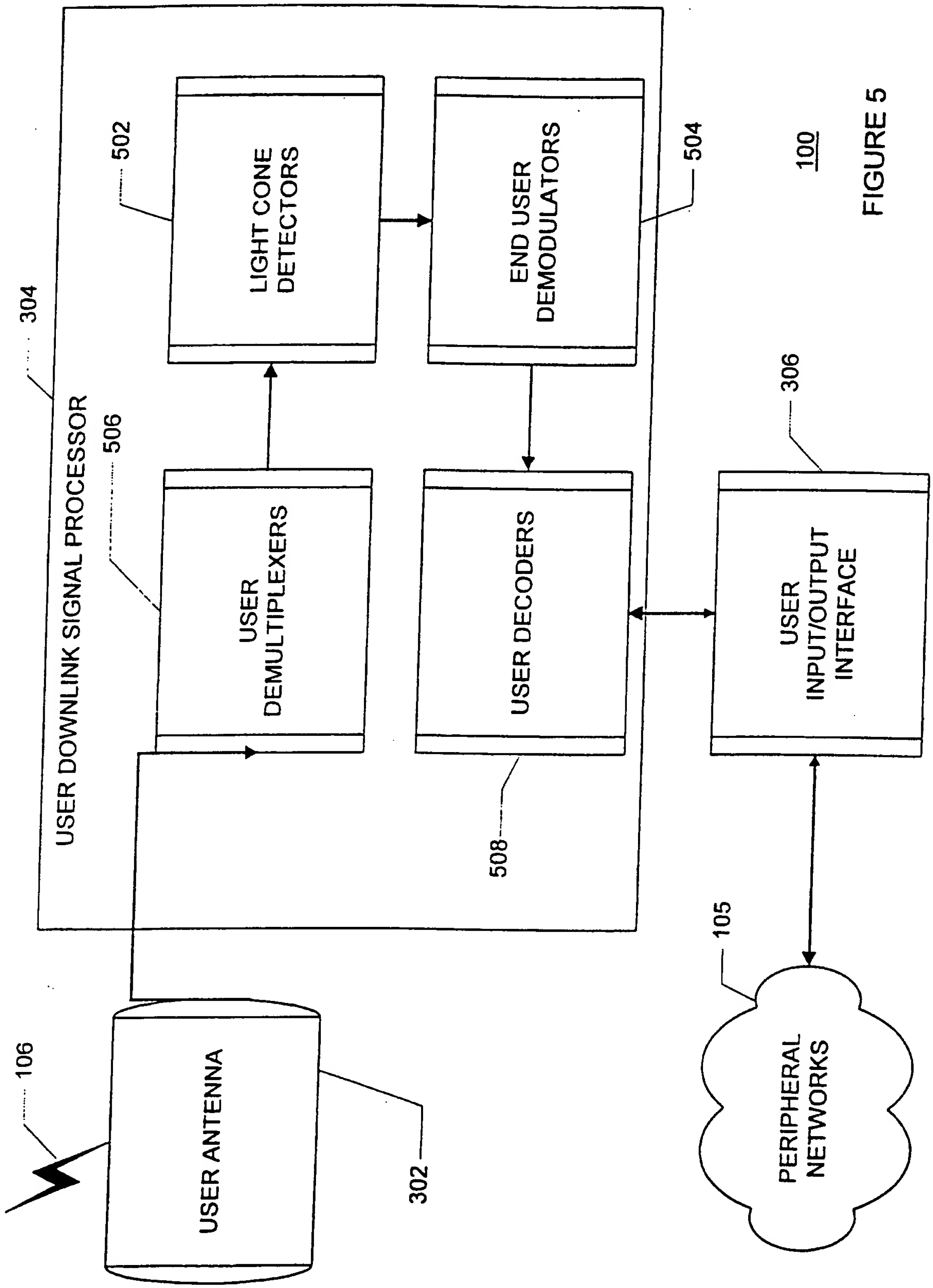

USER DOWNLINK SIGNAL PROCESSOR
304
LIGHT CONE DETECTORS
502
END USER DEMODULATORS
504
USER DEMULTIPLEXERS
506
USER DECODERS
508
USER INPUT/OUTPUT INTERFACE
306
USER ANTENNA
302
106
PERIPHERAL NETWORKS
105
100

FIGURE 5

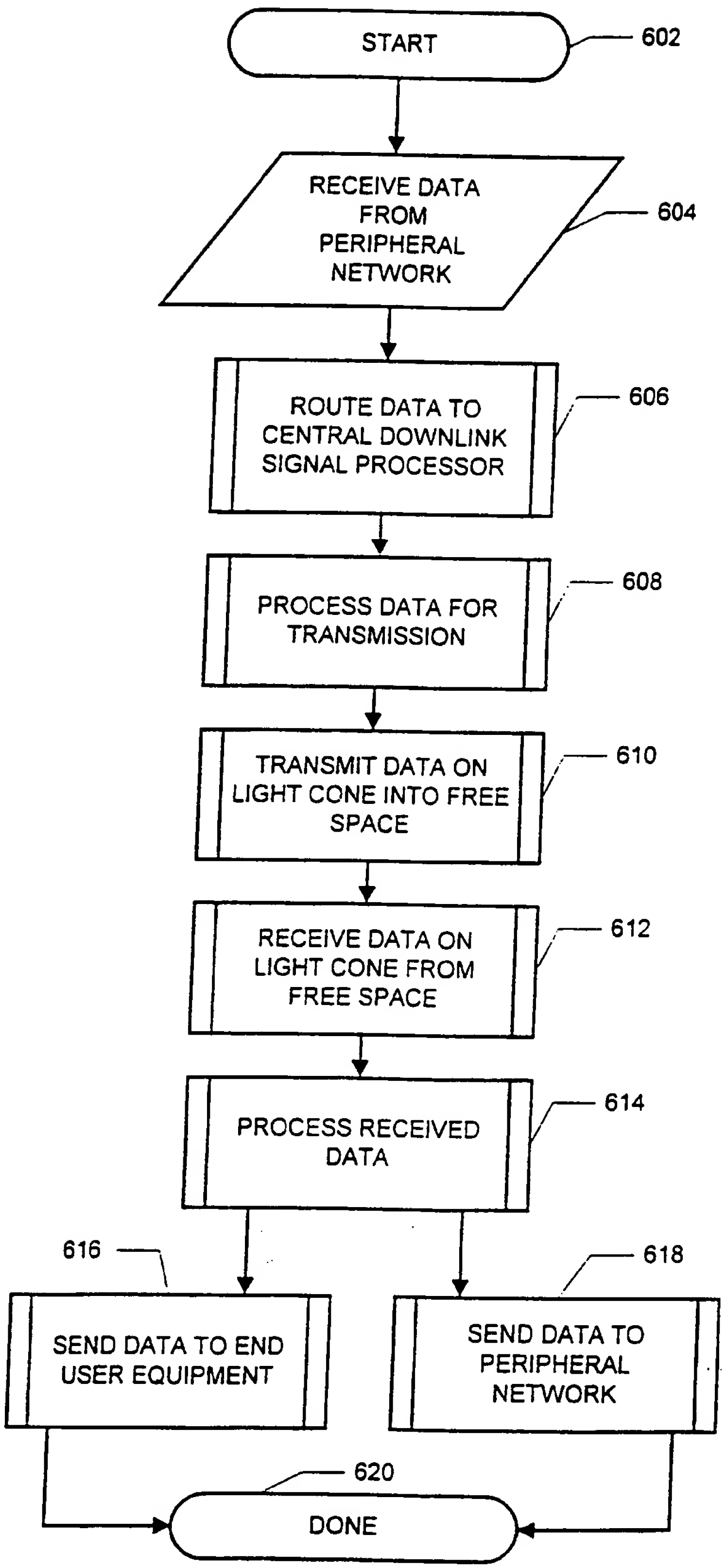


FIGURE 6

CENTRAL NETWORK RECEIVE FUNCTION 600

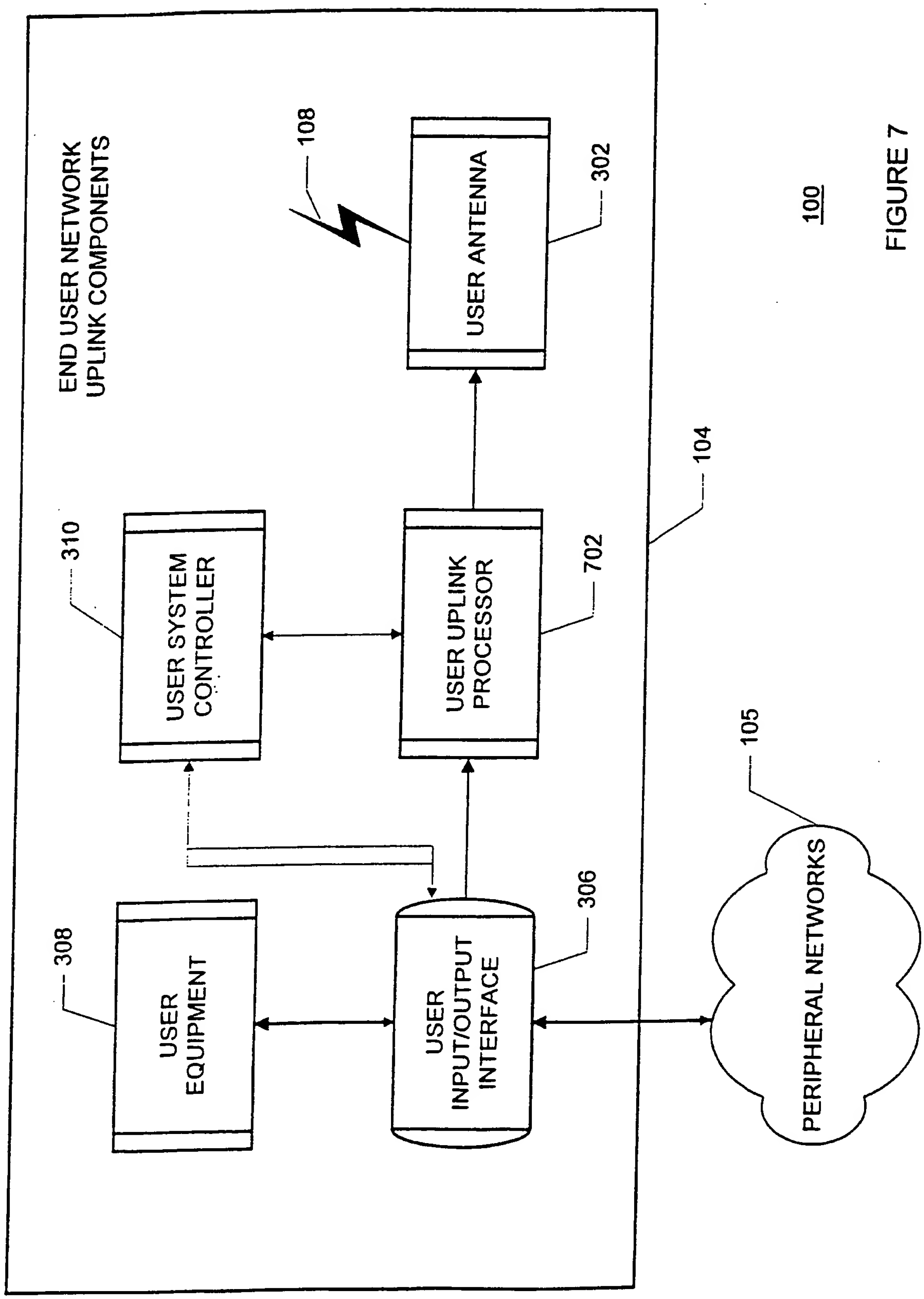

END USER NETWORK
UPLINK COMPONENTS
108
USER ANTENNA
302
310
USER SYSTEM
CONTROLLER
USER UPLINK
PROCESSOR
702
104
308
USER
EQUIPMENT
USER
INPUT/OUTPUT
INTERFACE
306
105
PERIPHERAL NETWORKS
100

FIGURE 7

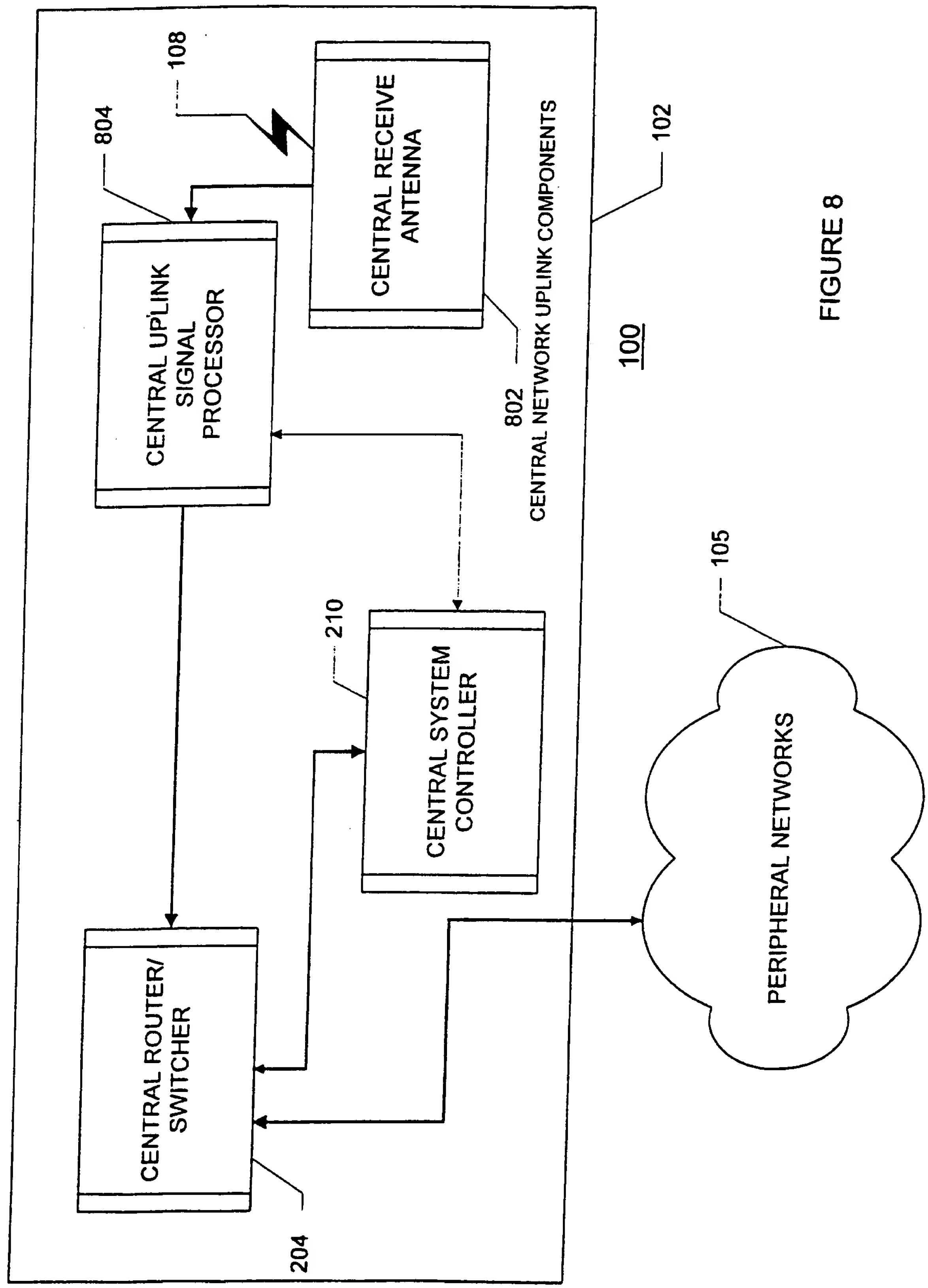

108
804
CENTRAL RECEIVE ANTENNA
CENTRAL UPLINK SIGNAL PROCESSOR
802
CENTRAL NETWORK UPLINK COMPONENTS
102
100
210
CENTRAL SYSTEM CONTROLLER
105
PERIPHERAL NETWORKS
CENTRAL ROUTER/ SWITCHER
204

FIGURE 8

FIGURE 9

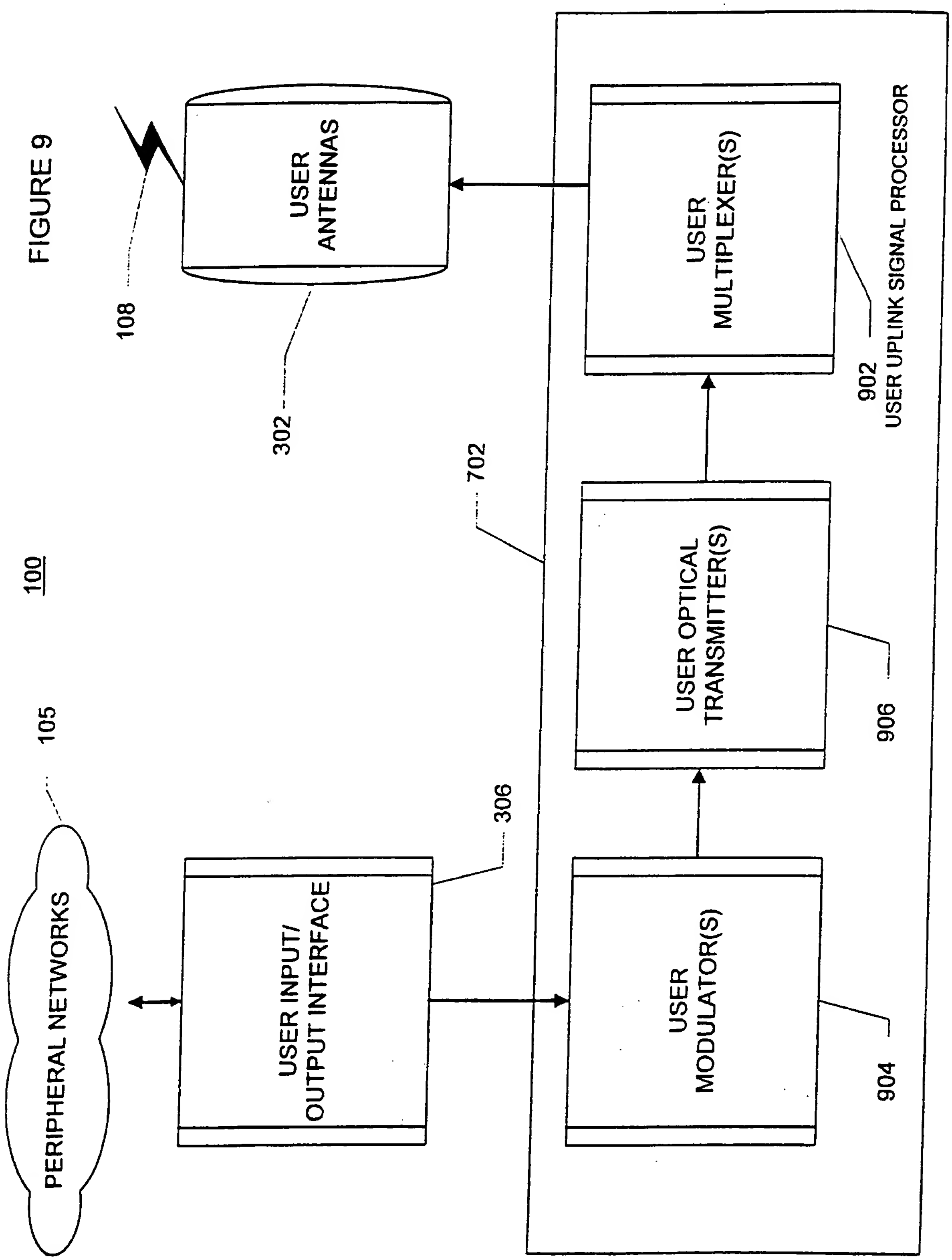
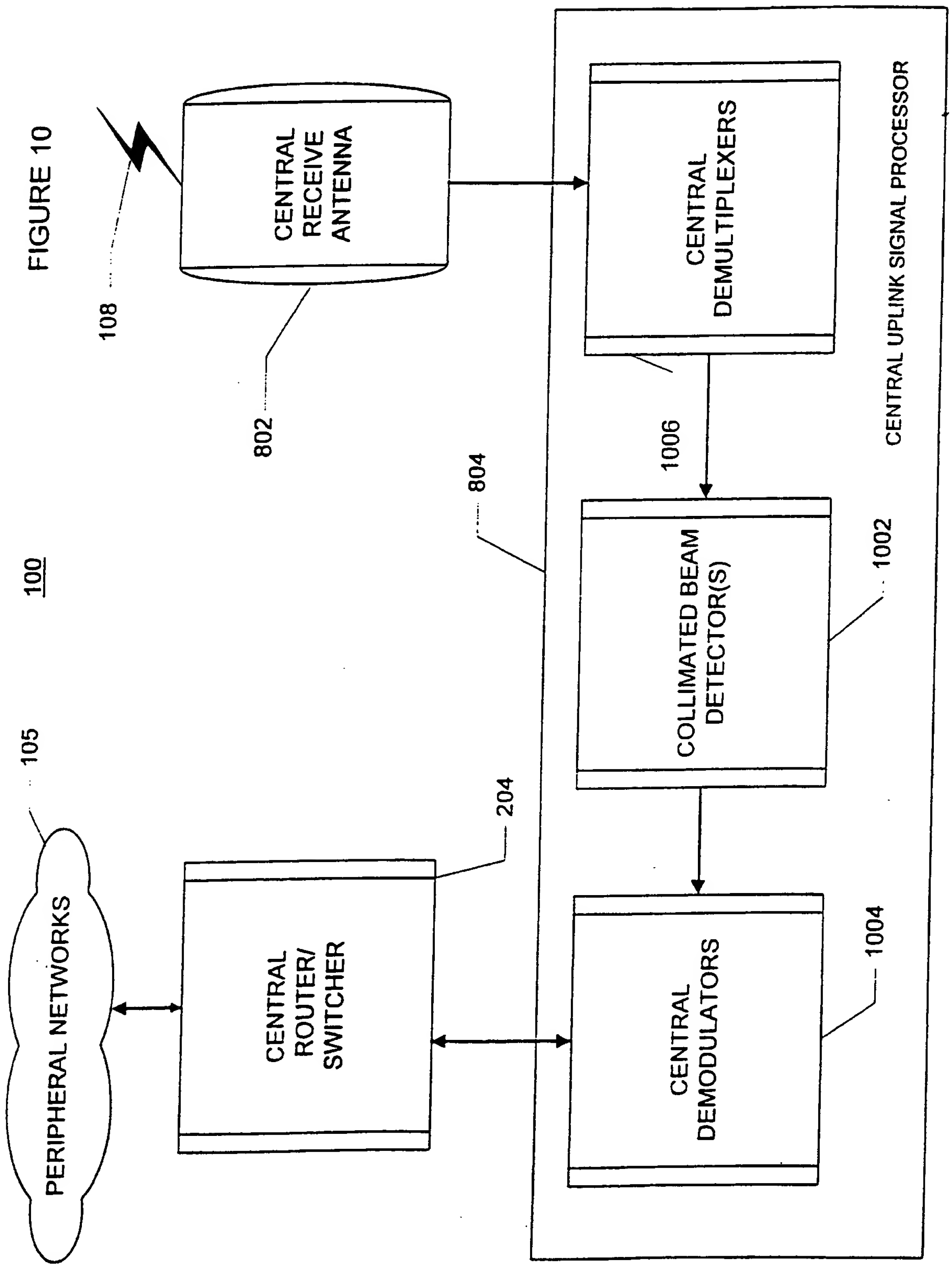

100
108
USER ANTENNAS
302
USER MULTIPLEXER(S)
902
USER UPLINK SIGNAL PROCESSOR
702
USER OPTICAL TRANSMITTER(S)
906
105
PERIPHERAL NETWORKS
USER INPUT/ OUTPUT INTERFACE
306
USER MODULATOR(S)
904

FIGURE 10


100
108
CENTRAL RECEIVE ANTENNA
802
CENTRAL DEMULTIPLEXERS
1006
804
COLLIMATED BEAM DETECTOR(S)
1002
CENTRAL DEMODULATORS
1004
CENTRAL UPLINK SIGNAL PROCESSOR
CENTRAL ROUTER/ SWITCHER
204
PERIPHERAL NETWORKS
105

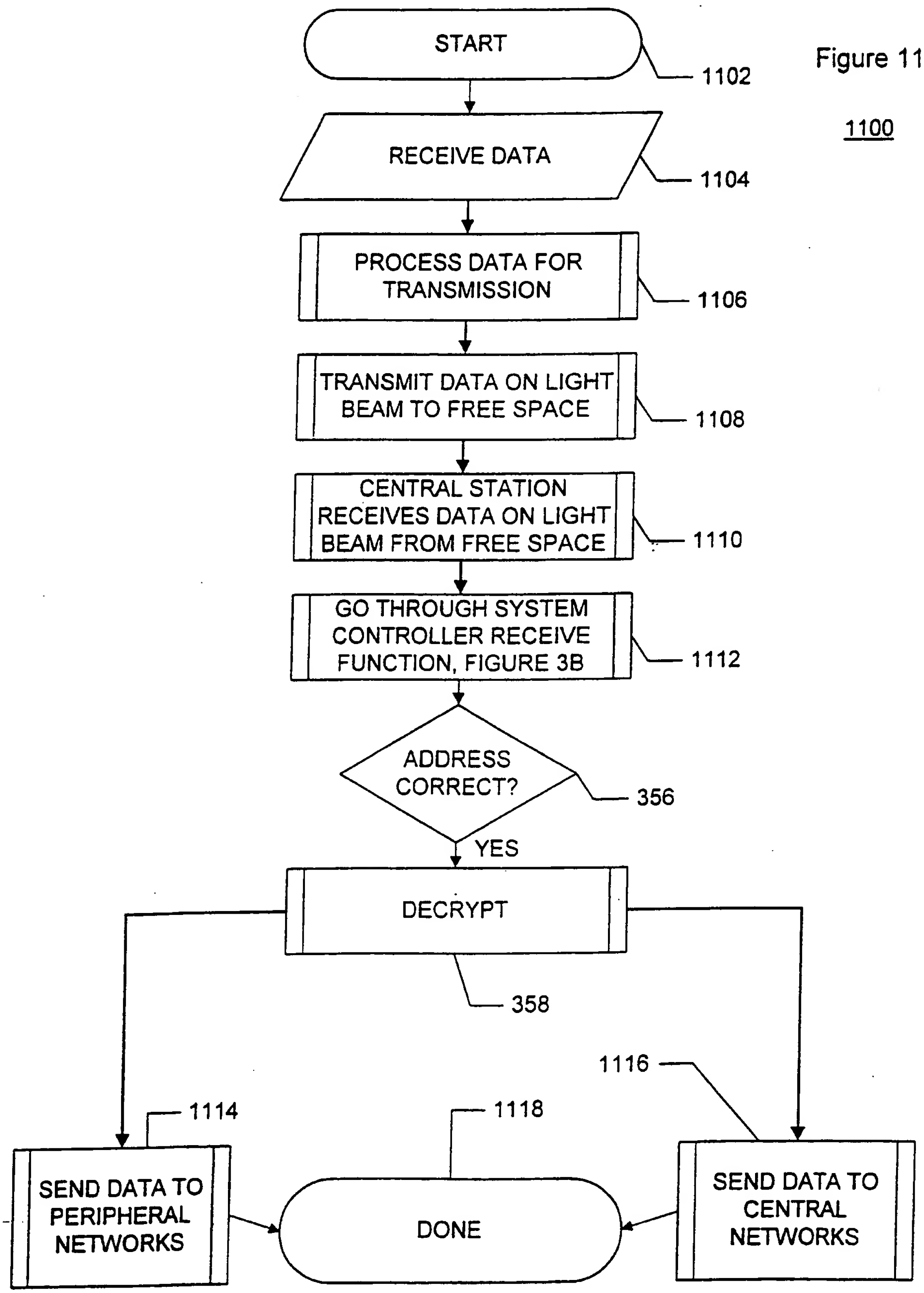


Figure 11

1100

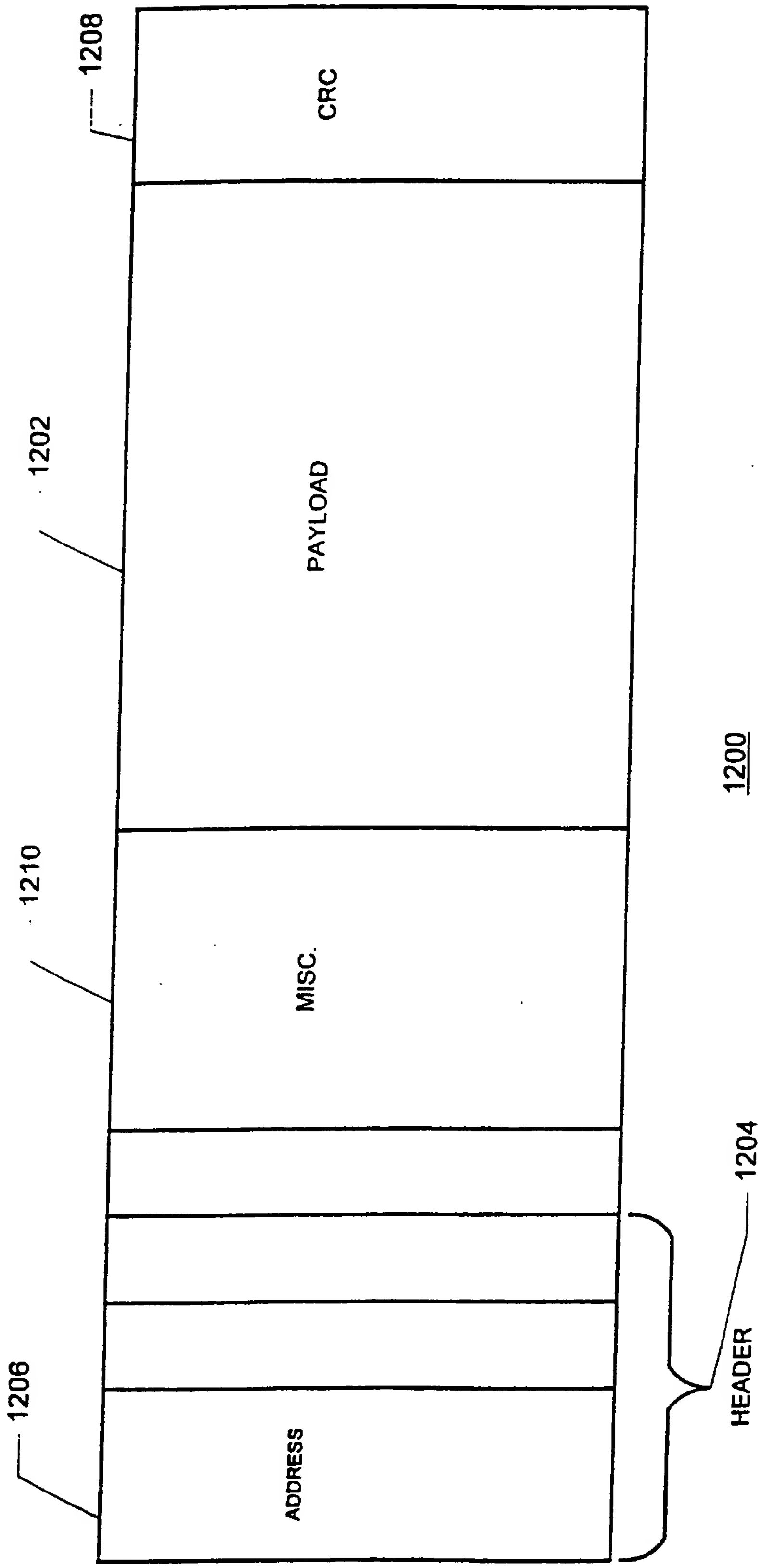

1208
CRC
1202
PAYLOAD
1200
1210
MISC.
1204
HEADER
1206
ADDRESS

FIGURE 12

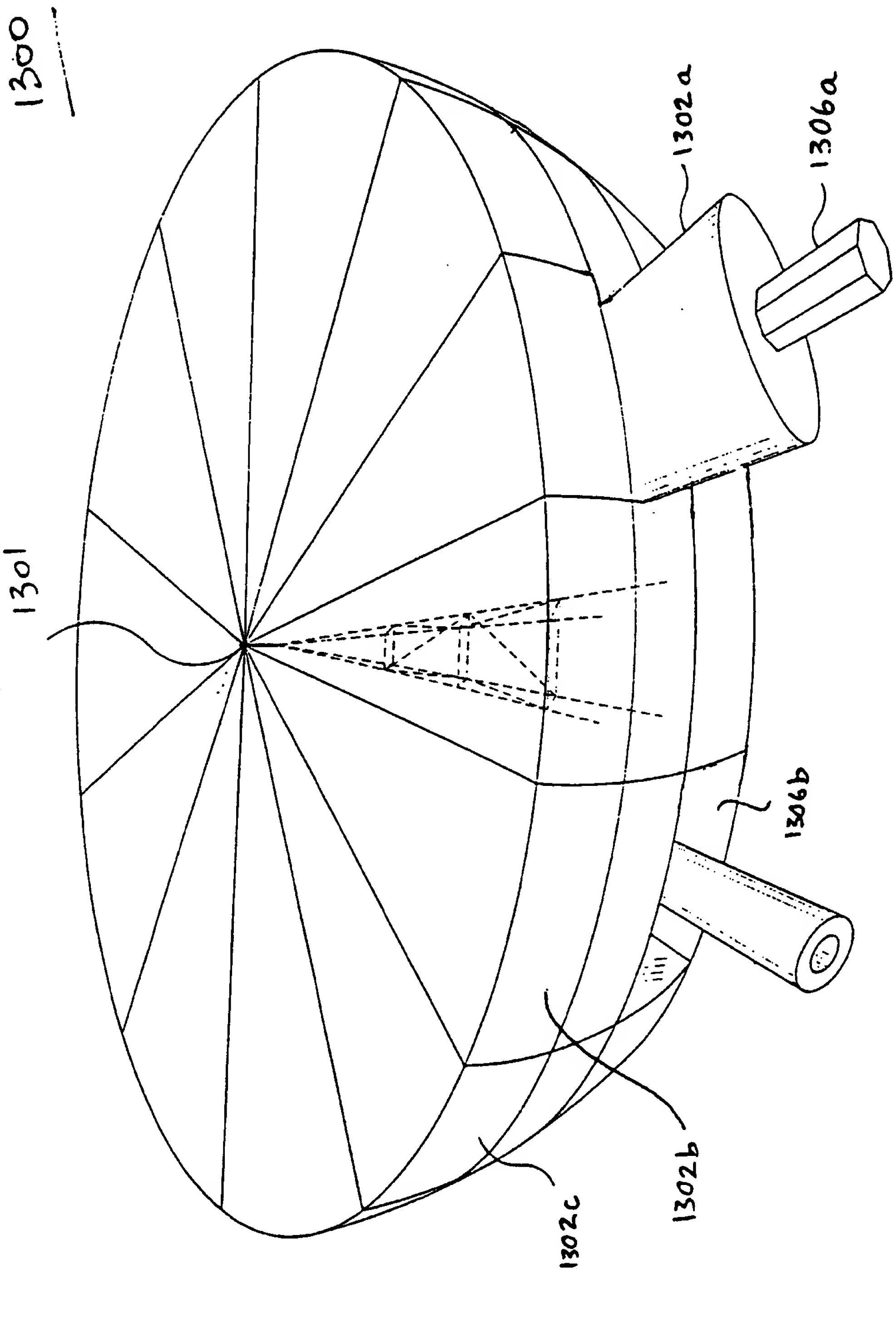


FIGURE 13

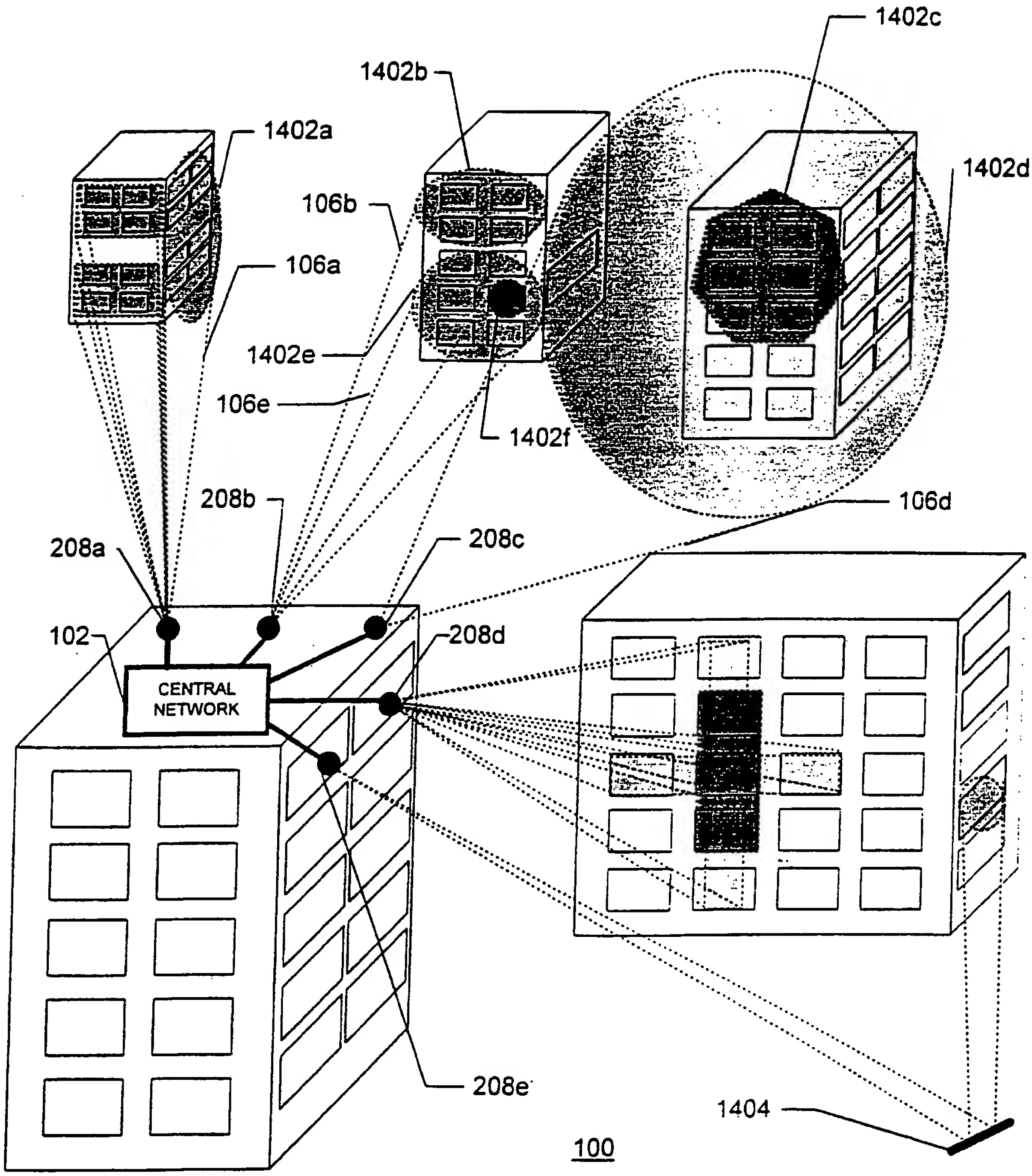

1402c
1402b
1402a
1402d
106b
106a
1402e
106e
1402f
208b
106d
208a
208c
102
208d
CENTRAL NETWORK
208e
1404
100

FIGURE 14

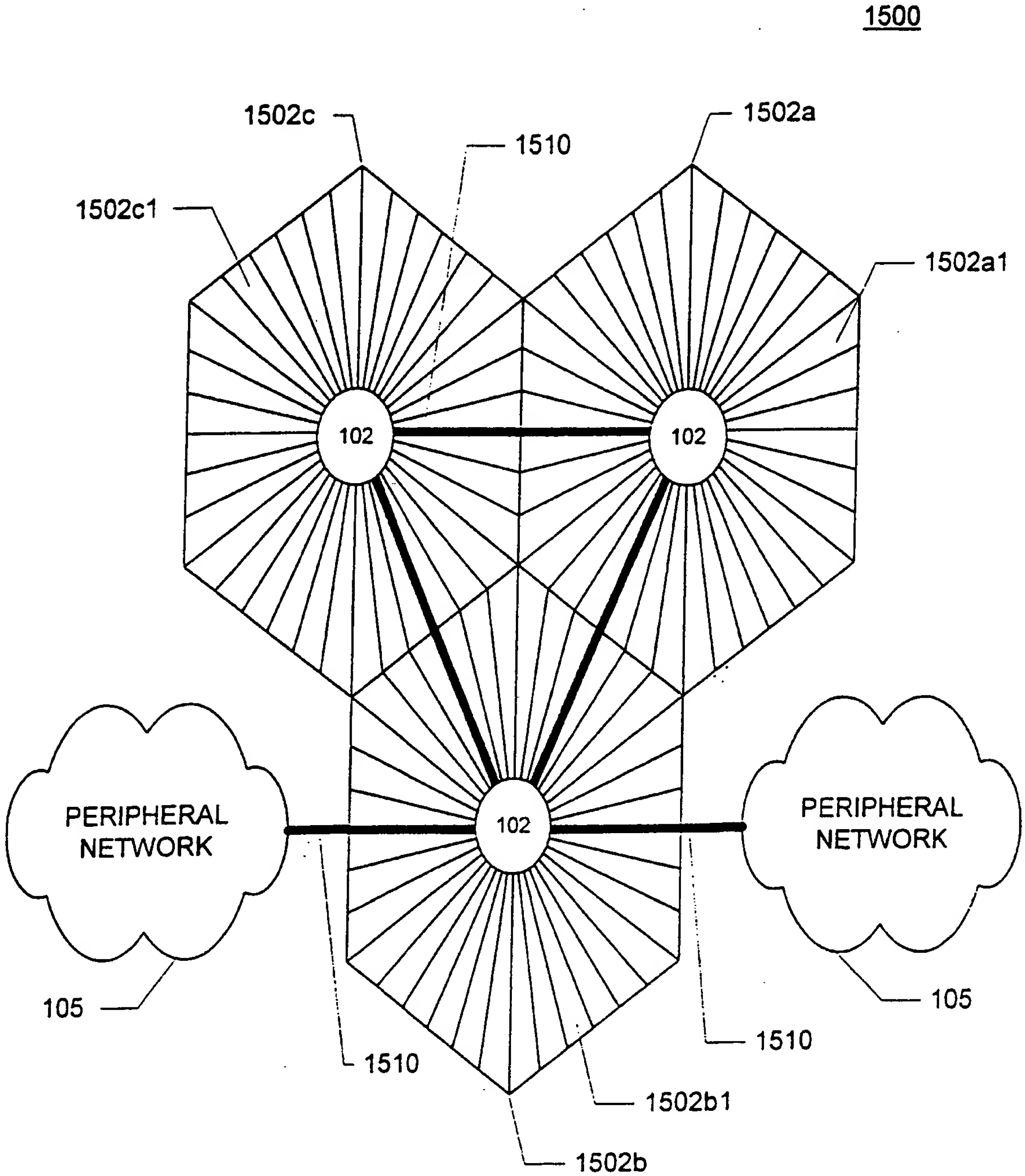
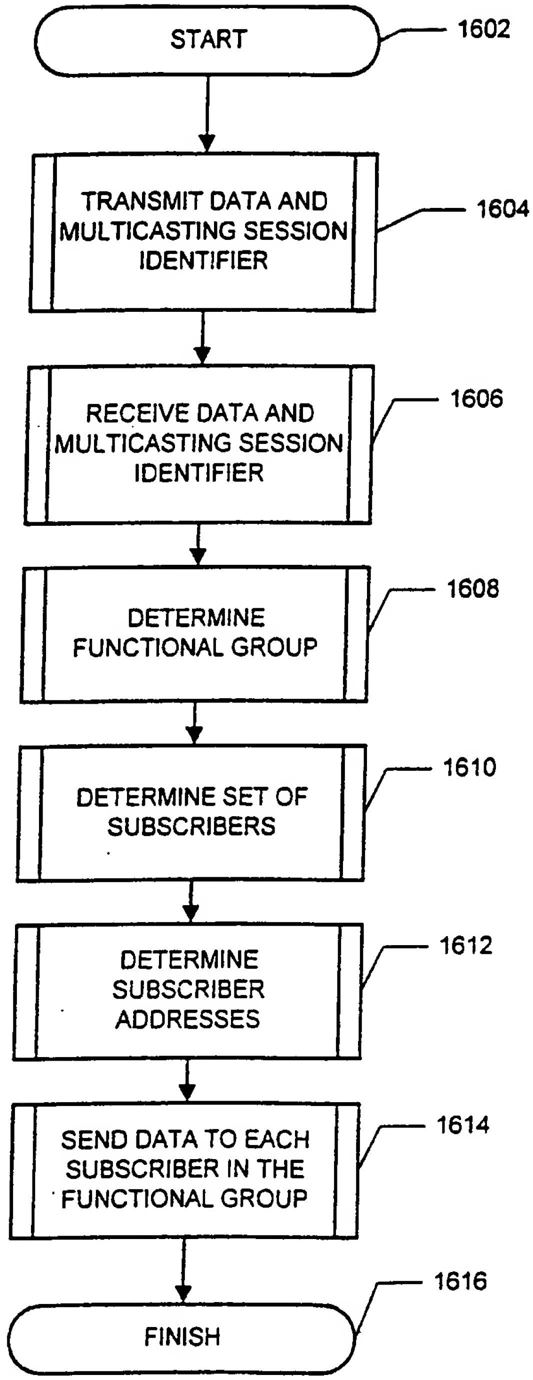

1500
1502c
1510
1502a
1502c1
1502a1
102
102
102
PERIPHERAL NETWORK
PERIPHERAL NETWORK
105
105
1510
1510
1502b1
1502b

FIGURE 15

FIGURE 16

1600



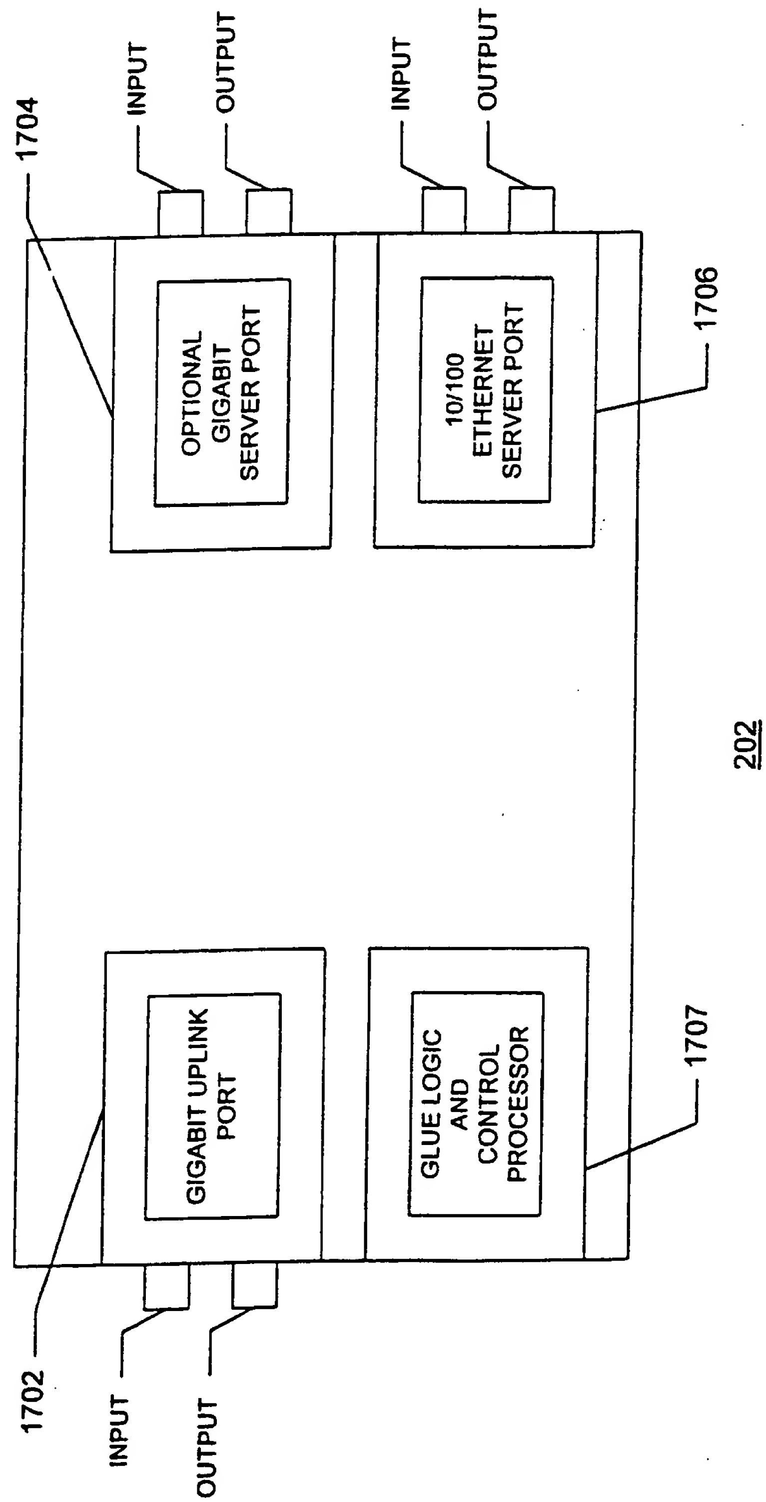

1704
INPUT
OUTPUT
INPUT
OUTPUT
OPTIONAL GIGABIT SERVER PORT
10/100 ETHERNET SERVER PORT
1706
202
GIGABIT UPLINK PORT
GLUE LOGIC AND CONTROL PROCESSOR
1707
1702
INPUT
OUTPUT

FIGURE 17

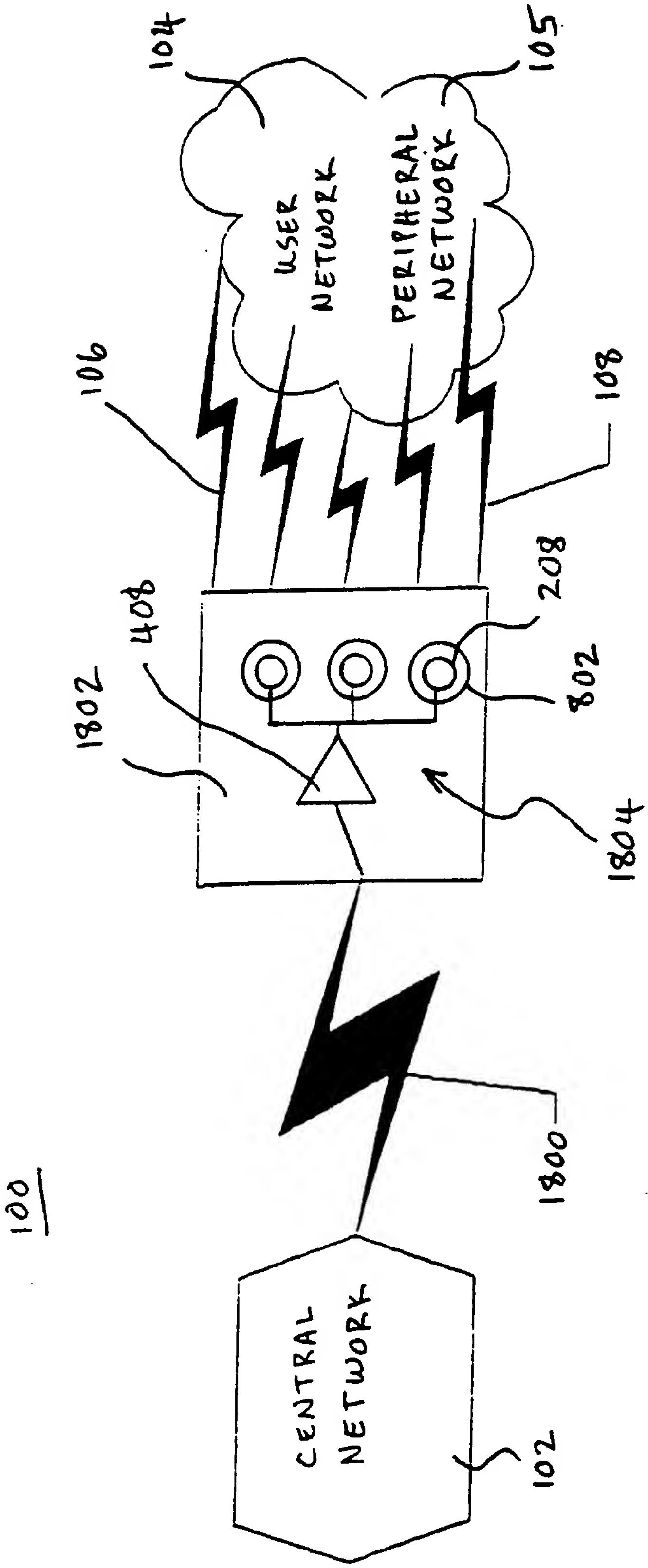

104
105
USER NETWORK
PERIPHERAL NETWORK
106
108
408
208
802
1802
1804
1800
100
CENTRAL NETWORK
102

FIGURE 18